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THE EVOLUTION OF THE SCIENCES

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BY

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TRANSLATED FROM THE FRENCH

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CONTENTS.

PREFACE

EVERY scientific book has three sorts of readers: experts draw upon it for information and facts, doctrinaires find arguments and laymen seek ideas in it. This book is not written for the first; it makes no pretension of presenting a summary of the results obtained by the sciences, and facts are cited only in so far as they tend to define the meanings and explain the origin of scientific ideas. Nor have I tried to settle the eternal dispute of religious and philosophical doctrines, to judge cosmogonies, or to throw light upon the origin and destiny of man and the universe. Experience proves that in this matter each one listens only to the arguments favourable to his standpoint and reads only the books on his own side. Happily doctrinaires are people easy to satisfy, provided one does not contradict them directly; they will find in these pages arguments favourable to their ideas and will not see those which contradict them.

But there are also men who, without being bound to a system, or seeking the eternal truths, try only to create a little light around them. They think that methodical and scientific investigation will bring them the only truth which they can attain; they ask from science neither recipes nor arguments; they seek the satisfaction of natural curiosity and the pleasure of understanding how the chaos of facts is organised gradually by the efforts of scientists. It is for such that this book has been written. I have tried to show them how the sciences shed light over an ever-widening circle. After having analysed the facts which are directly accessible to our senses, they make known to us others which had escaped them; like these rays which traverse bodies and show us their bony framework, they peer to the depths of the universe and teach us its extraordinary complexity. But they reveal to us law and harmony. Scientific progress is the product of this incessant ransacking of the unknown world, and of the coordination which every day becomes more close, of the facts acquired.

At the same time the Unity of Science

becomes apparent by the interpenetration of the sciences which, separate at first, unify progressively their experimental procedure, their methods and their principles. But this evolution is not haphazard. Mathematics form a primary connection between all our scientific knowledge, since it is woven by our mind and reveals the organic conditions of its activity. We cannot imagine a triangle the sum of whose angles shall not be two right angles, nor an equation of the second degree with three roots. But there is also a necessary logic of things existing outside our mind. It is impossible to heat a bar of iron without it expanding. That is a condition imposed upon the external world. We can recognise it without knowing what heat is, just as we can reason correctly without knowing the nature of thought.

Physics in its present-day broadened state teaches the necessary relations between external things, as mathematics reveals the rules of thought. From this point of view all experimental sciences are subordinate to it, just as our reasoning is subject to mathematical logic. Mechanics has its origin in experiments upon the

equilibrium and movement of bodies and still owes to physics all its subsequent progress, as regards, for example, the impact of bodies and friction. If at the present day even its principles seem to be undergoing transformation to such an extent that the notion of mass is losing the exact meaning which it had previously,[1] the cause must be sought in the recent researches upon radio-active substances. Astronomy on its side, after being satisfied for long with the experimental laws of gravitation, has taken a new development, laying under contribution all the resources of modern physics for the study of celestial spaces, and gravitation itself has become one of its most pressing problems.

Geology no longer limits itself to the study of rocks and formations. To reconstitute the history of the globe, to determine the constitution of its deepest strata, it must make appeal to our ever-deepening knowledge of the laws which rule matter, heat and magnetism. It is the same with all the biological sciences. They are face to face with the most redoubtable of

[1] *Cf.* Chap. "Does matter exist?"

problems, the problem of life. They circumscribe it little by little, reducing certain phenomena to physico-chemical laws. Science gains progressively upon mystery; it is not forbidden to hope that the day will come when the great enigma will be deciphered in its turn. But no science has formed a closer alliance with physics than chemistry. They have the same object, principles and methods, and it is impossible to say where the one finishes and the other begins. Merged one in the other they collaborate in a common task.

Thus physics has been the mainspring of the other sciences, has imposed upon them its laws, its methods and its experimental procedure. Nowadays every well-constructed experiment is necessarily a physical experiment. It is in this way that the unity of science is made and that is the chain which links the sciences together. It is useful to recognise the fact, not only in order to comprehend the evolution which is so characteristic of our epoch, but also to solve a difficulty which results from this evolution.

Step by step with the creation of unity in

our minds, a greater diversity separates those who instruct, or have charge of, their progress. Specialisation is the evil of the age, the price of progress. Past ages have had men of universal knowledge, Leonardo da Vinci, Newton, Leibnitz and Laplace, whose minds embraced all the knowledge of their age. Undoubtedly the last of those encyclopædic geniuses was Berthelot, and he has lately recognised it with mingled feelings of pride and regret. Our brain is too small to contain the growing mass of knowledge. Must we then each sink his own shaft, toiling blindly on, heedless of the work of others? Such is the disquieting problem which we face, and which we must answer at any cost.

The foregoing observations show where the solution is to be found. Since, to-day, no mind can retain all the sciences, all specialisation must be preceded by an infusion of general science, giving the conditions of our reasoning and of the external world. Mathematics and physics are the veritable "humanities of science." They form the indispensable basis of all study bearing on any science whatsoever, and it is

logical and necessary that our education be organised accordingly.

Such are, in brief, the ideas developed in this book, which give to it also unity. I hope they will obtain the approval of the readers for whom I have intended them, readers who regard with interest the workings of the universe, and who believe that science alone permits of our understanding somewhat of its function.

PREFACE TO THE ENGLISH EDITION

NOT with immunity have nations lived, for centuries separate, the one from the other. Their minds have developed along separate lines, and given to each a characteristic turn of thought, and a logic almost individual.

This individuality of each nation is articulated not only into their literature; it is found also in their scientific productions. Without exaggeration it might be said, England sees everything in the form of a mechanism, Germany in that of a formula, whereas France prefers to give its ideas as reasonings. This diversity is not without its advantages, for the unity of scientific truth is like a diamond which gains by being illuminated by every facet. But this advantage only exists where each nation, true to its own genius, takes the trouble to look abroad. This will always be to its profit.

It would take too long to tell all the benefits which French physicists have derived from scientific intercourse with those of England. In

electricity their ideas have been completely remodelled under the influence of Faraday and Maxwell. To take a recent instance, our ideas on radio-activity would not have developed so quickly had it not been for the daring hypotheses of Lodge, Rutherford and J. J. Thomson.

I am pleased to think that this scientific intercourse is profitable for all nations, and for this reason I bring my modest contribution with pleasure to this international exchange. I have no intention to teach scientists anything. I only wish to interest those who love science as outsiders in the general ideas which form the atmosphere of the laboratory and, above all, to make them familiar with that superior form of common sense which is called the scientific spirit.

As a rule the French genius prefers lucidity to depth. It will not be satisfied till it has reduced ideas to their simplest form. Further, a lengthy training in literature has taught it that lucidity can only be obtained by order, by methodical exposition rising from the known to the unknown, from the simple to the composite.

Preface to the English Edition

These are the essential qualities of popularisation.

I have endeavoured to make them those of my work. At the same time I have tried to defend the mind of the reader against a species of scientific bluff which is, no doubt, rampant elsewhere than in France, and which consists in representing scientists as magicians who dispose of the physical world at will. No day passes without some great discovery being announced. We must teach distrust in these marvels which are boomed so loudly and gain a hearing for voices which are more discreet and thoughtful.

Such is the end I have kept in view in this book. I feel highly honoured to see it received in a country which has done so much for science. I hope my English readers will reap some benefit from the general ideas expressed in it, and from the directions for the scientific spirit which I set forth.

L HOULLEVIGUE.

THE EVOLUTION OF THE SCIENCES

THE TENDENCIES OF CHEMISTRY

ALL the experimental sciences have passed through three successive stages. First comes a long chaotic period, during which the data of observation and experiment float without order or connection in the mass of human knowledge, the whole forming, as it were, a great nebula which, when the time comes, condenses round separate nuclei. Between the Renaissance and the end of the eighteenth century the sciences were separating and crystallising out. Each science defined the goal of its researches, delimited its domain and organised itself internally by the continual acquisition of new laws. At the present day we are entering on the third stage: the sciences, separate in the

past, interpenetrate one another, and through their broken-down partitions we perceive the gradual growth of the Unity of Science.

Chemistry has not evaded this general law. The facts of a chemical nature known to antiquity and the Middle Ages, do not, however numerous, deserve the name of science. One may, if one likes, trace back the first chemical reaction to Prometheus, the inventor of fire, or to Tubal Cain, the sixth man after Adam and the creator of metallurgy; but a thousand reactions no more constitute chemistry than a thousand words strung in a row haphazard form a phrase or an idea. Until the eighteenth century chemistry was limited to a technique scattered over the useful arts; one finds it in the processes of the artisan, in the pharmacopœia of the doctor, in the operations of the magician, the thaumaturge, and the alchemist, in the tricks of the charlatan. Professional chemists were mere compilers of such processes; Glaser, in 1670, defines chemistry as "the art of opening compounds by operations, consisting in cutting, bruising, pulverising, alcoholising, scraping, sawing, precipitating,

-anulating, laminating, melting, liquifying, gesting, infusing, macerating," etc.

Berthelot has given us a masterly account[1] this long period of gestation, when human ought, so full of life in every other respect, ems, when confronting science, sunk in a eam-broken sleep. We owe him special anks for having pointed out the paths along iich this dust of science may have been transtted from age to age across the civilisations India, Egypt, Greece and Europe, which form it were oases in a desert of barbarism.

The seventeenth century, thanks to the rts of Galileo, Torricelli, Descartes, Pascal l Newton, saw the birth of mechanics, onomy and physics. Then came the turn chemistry; only a collective effort could it into existence. When in a space of nty years one sees crowded such names as stley, Cavendish, Bergmann, Scheele, Four-, Lavoisier, one realises that the world was ied away by an impulse of scientific realism. Probably no science ever owed so much

[1] *Les Origines de l'alchimie*, 1885. *Introduction à l'etude de mie des anciens et du moyen âge*, 1889.

to a single man as chemistry does to Lavoisier. He freed it from the last trace of metaphysics, gave to the notion of element a precise meaning, and gave expression in the chemical equation to one of the essential elements of chemical reaction. The work of Richter and Proust left chemistry with a complete skeleton: the existence of elements, the conservation of matter and the existence of simple ratios in combinations; what remains is, as a matter of fact, simply physics.

Thus classical chemistry was evolved in the course of a few years; it is the chemistry we all have studied and it is still taught, more or less, by the most recent text-books.

Let us take up one of these books. We find that it commences with some pages of generalities setting forth in a clear and general form, with the timely help of the atomic theory, the experimental principles of the science of chemistry. Then the student is initiated into the principles of nomenclature, which enable the objects studied to be clearly designated; but every nomenclature assumes a classification and we now perceive that classical chemistry is chiefly

descriptive. Its objects are the same as those of natural history with Buffon and Linnæus. Chemical species, like living ones, are designated by a binary nomenclature; we say *potassium sulphate* as we say *Felis leo.* Having provided his classification with the orders and sub-orders necessary for a methodical organisation of his work, the chemist gets to business; as the naturalist classifies his plants between the leaves of an herbarium and arranges his animals in glass cases, so the chemist lays in a stock of bottles, and from that day his aspiration is to fill each bottle with a definite product, preferably crystallised. (Amorphous bodies are impure and uninteresting in his eyes.) The text-book of classical chemistry, true to the spirit of the laboratory, will fill its hundreds of pages with descriptions of the chemical species which we have seen labelled in the laboratory, and teach us in rigid sequence the manner of their preparation, the analysis to test the purity of the product, their physical, organoleptic, and finally their chemical properties—that is to say, the manner of their action on various other bodies. So the reader

sees defiling before his eyes a series of colourless, tasteless and more or less liquifiable gases, and bodies which colour differently litmus paper.

We need not be surprised if students do not enjoy eagerly a teaching so exclusively descriptive, a mere long and monotonous review of elements and compounds. But official programmes and classical books at least show us, magnified to deformity, the essential character of classical chemistry; this science aims principally at being a description of chemical species, a study of the forms of equilibrium of matter at ordinary temperatures. This is so entirely true that one of the works most justly valued by chemists, that of Würtz, assumed as a matter of course the form of a dictionary; a sufficiently reasonable arrangement for a science composed of monographs, but whose application to mathematical analysis, mechanics or physics could hardly be conceived.

We must not permit the endless profusion of monographs to surprise or to irritate us. It was necessary for chemistry to follow this course at the outset, and to draw up the inventory of the domain within which it had to evolve.

Natural history commenced in the same manner, and the work of Buffon and Linnæus was not useless, though it may to-day appear very tedious to us. We consider, at present, that the essential interest of these sciences is the study of life in action—that is to say, vegetable and animal biology. The same reasons lead us to say that classical chemistry, while confining itself to nomenclature and to the study of forms, deliberately neglected the fundamental problem—that is to say, the study of reactions. In a reaction it merely recognised a period of disturbance which had to elapse before a new state of equilibrium could arise, and it hurried over these periods as some historians with a mania for order are wont to do with the story of revolutions.

When, for example, in the formula

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$

it summed up the action of sulphuric acid on zinc, the investigation centred its entire attention on the state of the bodies before and after the reaction; it told us all about their properties and about the quantities involved, and then with the brief sign = closed the discussion.

Thus classical chemistry consists almost entirely of chemical notation; when it has written the equation of a reaction it is satisfied that nothing remains to be told, and the succession of its monographs are in their turn condensed into structural formulæ. All its efforts are directed to the establishment of these formulæ, they are its supreme object; it is, in fact, impossible to conceive a more elastic and expressive manner of representing a body. Take the formula of alcohol:

$$
\begin{array}{ccccc}
 & \mathrm{H} & & \mathrm{H} & \\
 & | & & | & \\
\mathrm{H}- & \mathrm{C} & - & \mathrm{C} & -\mathrm{H} \\
 & | & & | & \\
 & \mathrm{H} & & \mathrm{O} & -\mathrm{H}
\end{array}
$$

It discloses the qualitative and quantitative composition of this body and its vapour density, it shows its essential properties and the action exercised by it on most other bodies, and all this without the intervention of a single hypothesis; if we further admit the atomic conception of matter our formula presents an image of the molecular structure built up of the atoms of the elements; in fact, so

numerous and so precise are the conclusions which may be drawn from these calculations that in the case of certain series of bodies the mere examination of the formula enables us to determine exactly all their physical constants and to predict even their colour.

Descriptive chemistry is ~~on~~ no dead science, it is alive and is developing under our eyes. Of the two thousand memoirs regarding the chemistry of metals, which annually sum up the chemist's work, over three-quarters are devoted to new or imperfectly-known compounds. For a chemist who knows his business it is a comparatively easy, almost a mechanical task to fill the gaps in series of compounds or to study in a state of increased purity bodies previously known. The hope of industrial or therapeutic applications stimulates the zeal of the discoverers of new bodies, and these hopes find their justification in the four hundred patents taken out every year for industrial applications of chemistry.

The recent progress of physics has also thrown open to classical chemistry a domain full of interest. Until quite recently chemists

were compelled by their inability to obtain permanent high and low temperatures, to confine their attention to compounds which remain stable at laboratory temperatures. 7,776

To-day we can maintain as long as necessary, in a space of several cubic decimetres, temperatures ranging from two hundred degrees below zero to three thousand five hundred degrees centigrade above it; the use of liquid gases and of the electric furnace has rendered this service to science; and our day has seen the rise of the chemistry of intense cold and of intense heat. The names of Ramsay and Dewar are associated with the former by their discovery and separation of the constituents of the air, argon, neon, krypton, xenon and helium, while the latter has rendered famous one of the great names whose loss French chemistry and science are mourning to-day—Moissan, one of the most skilful experimenters known to chemistry, a true representative of classical chemistry; his isolation of fluorine, his studies on the diamond, but chiefly the marvellous series of *carbides* and *nitrides* obtained by means of the electric furnace, have made his name justly famous. But for

Moissan chemical reactions were simply a means; his object was to obtain new bodies, or to produce, under new or more favourable conditions, previously-known bodies.

Though he set himself a limited task he completely fulfilled it, and there is a lesson to be learned from the results which he obtained. Until recently there has been an undue tendency to think that at very low temperatures matter must be more or less congealed and incapable of manifesting its activity in the form of chemical reactions, and that, on the other hand, at very high temperatures bodies are dissociated by heat and remain a mere aggregate of simple elements incapable of reaction. We know, to-day, that such is not the case, and that, unlike life, chemical activity is not confined within narrow limits. Matter presents different forms of equilibrium at different temperatures; and the number and variety of possible chemical combinations is thus so enormously increased that we are forced to find slight and insufficient the old law of simple ratios, which pretended to limit the number and the variety of molecular constructions.

When we consider that five hundred combinations are actually known of two bodies alone, carbon and hydrogen, when we think of the millions of compound bodies which we are to-day able to produce with seventy-two elements, we are compelled to admit that the inventory drawn up by classical chemistry, was no useless or idle task, because it has left us not only an arid nomenclature, but a deeper knowledge of the properties of matter and of the general conditions of molecular association.

From the beginnings of chemistry as a science a fundamental distinction was made between the products of mineral matter and the products of life, elaborated by animals and plants. This separation between organic chemistry and inorganic chemistry increased with the progress of the science to such a degree that chemists were forced to the conviction that it rested on the very nature of things. These two branches of a single trunk grew steadily wider apart, developing in different degrees, one branching out with rapid and faultless order, while the branches of the other remained ir-

regular and short. And yet organic chemistry, working almost exclusively with four elements—carbon, hydrogen, oxygen and nitrogen—seemed less amply equipped than mineral chemistry which has the entire array of simple bodies at its disposal. What is the cause of this unequal development?

The very nature of the forces called into action used to be the chemist's reply; living nature has endless resources, which can never be available in a laboratory, and life is accompanied by specific processes, which by their very nature are beyond our reach; man can destroy molecules, but Nature alone can fasten the delicate bonds of organic compounds. This view rested on the authority of Lavoisier himself, who, a few days before his death, had written: "The object of chemistry, in submitting to experiment the different natural bodies, is to decompose them and find itself in a position to examine separately the different substances which enter into their composition. Chemistry, therefore, advances towards its object and its perfection by dividing, sub-dividing and sub-dividing again."

Such was the state of ideas when Berthelot, in 1851, entered as Bolard's assistant at the Collège de France on a scientific career destined to be most prolific. He placed at the service of science not only technical skill and power of work in a degree rarely combined, but the true characteristic of his genius resided in a faculty still more rarely found in the laboratory—a thorough philosophical education and a mind inclined towards generalisation. His philosophic ideas led him to perceive *à priori* the weakness of a doctrine that restricted chemistry to the function of an analytical science and erected insuperable barriers between the work of Nature and the work of the laboratory. It is true that organic syntheses had been made before Berthelot, but to him belongs the honour, one of the highest in his scientific career, of erecting into a system and a doctrine what before was merely chance and good luck.

He created order in organic chemistry by establishing, experimentally, the connection of the different series of bodies belonging to it; but it was chiefly by showing, in numerous cases, the possibility of passing from inorganic matter

to the products of organic matter that he constituted the Unity of Chemistry and expelled "vital force" from the language of science along with the mysterious actions which had concealed our ignorance. At the same time he opened to science a wide avenue, now thronged by a horde of workers. In our day the continuers of his work of synthesis are chiefly to be found in Germany. In another chapter we shall show how we are on the eve of the synthesis of protein bodies, which are not like alcohol or formic acid, waste materials or reserves, but the very substratum of life. In France also, besides the master who provided chemistry with the leading idea, other chemists consolidated the doctrine by contributing new facts; some of them have lessened the distance between organic and inorganic chemistry by adding to the elements of the former silicon, sulphur and the metals; others, by developing the atomic theory, have shown that the mode of representation which it offers applies equally well to all parts of chemical science. Hence, to-day, chemistry, in all its branches, forms a whole, derives from the same principles and obeys the same laws.

The description of chemical species is not the sole business of chemistry; a new branch is growing up slowly and logically, which looks for matter where it is really alive, that is to say in chemical reaction. Physicists have sometimes been reproached for "amusing themselves by weighing flies' eggs in cobweb scales;" but whoever has seen a chemical reaction—an object on fire, an acid and a base reacting—cannot help opening his eyes and inquiring the reason of all this disturbance and display of energy, and what is happening behind these appearances. Thus the study of reactions is not the accessory but the very essence of chemistry.

Such is the idea which to-day is leading chemistry towards new fields. Certainly it is not a new idea; it has occurred beyond doubt to all who since the beginnings of chemistry have witnessed matter in reaction. Boerhaave even invented a word, affinity, to designate the mysterious cause of chemical reactions, while Bergmann, a little later, drew up tables of affinity, on the supposition that the power of combination of each body could be expressed

by a number. But among these pioneers Berthollet, a contemporary of Lavoisier, deserves a distinguished place. During the Egyptian expedition, on which he accompanied Bonaparte, Berthollet conceived the plan of his *Chemical Statics*, a work in which are to be found the first sound ideas on chemical reaction and the origin of modern chemistry. Berthollet's only mistake was to arrive too early on the scene. Classical chemistry, firmly wedded to the idea of definite combinations, was then in process of development; it could not, without risk, abandon the solid ground on which Lavoisier had placed it; that is why sixty years passed before it was possible for the ideas of Berthollet, in their turn, to take root and grow.

The study of chemical reaction is a necessity; but how is it to be attacked? From what side are we to approach the problem? Two paths were open to the investigator; the first, indicated by Bergmann, was followed in 1854 by the Danish chemist, Julius Thomsen, and broadly marked out by Berthollet and his followers of the French thermo-chemical school.

The second, developed from the theoretical ideas of Berthollet, was opened in France by Henri Sainte-Claire Deville, and continued by the Dutch and German physico-chemical school, of which Van t'Hoff is the acknowledged leader.

The conception of chemical affinity remained to some extent incomplete and indefinite until the conception of energy and the principle of the conservation of energy made their appearance in science. Towards the middle of the nineteenth century it began to be seen clearly that natural phenomena invariably imply the transformation of a single entity appearing in the form of mechanical work, electricity or heat. It was natural to include in this catalogue of the various forms of energy the force which appears in chemical reactions and is betrayed by its mechanical effects when gunpowder explodes, by an electric current in the cell and by the production of heat in most other cases. Henceforth the affinity of zinc for sulphuric acid acquires a definite meaning; it is measured by the heat released in the reaction of the molecular weights of these two bodies. Thus the course to be followed is already set;

we need only reproduce within a calorimeter all the reactions known to chemistry, and measure the quantity of heat set free in each case. We shall then have a precise and scientific substitute for Bergmann's tables, and our results will act as a check on each other; or better still, from a number of them we can calculate the rest.

It is, of course, impossible for us to measure the total energy contained in bodies; we can know only the variation of this energy during the act of combination; thus the energy of the molecular weight $H_2=2$ grammes of hydrogen is just as unknown to us as the energy of the molecular weight $O=16$ grammes of oxygen; but we do know that when these two weights combine to form aqueous vapour 58,300 calories are released. We are, therefore, entitled to say that a molecule of water vapour has 58,300 calories less energy than its constituents, and to complete Lavoisier's chemical equation as follows:

$$H_2+O=H_2O+58{,}300 \text{ calories.}$$

Let us now consider a slightly more complicated reaction, that of sulphuric acid on zinc:

$$Zn+H_2SO_4=ZnSO_4+H_2+107{,}000 \text{ calories.}$$

It leads to the following argument: as the heat of formation of sulphuric acid, from its elementary constituents, amounts to 123,000 calories, the first member of the equation possesses an energy equal to that of its free constituents, less 123,000 calories; likewise the group forming the second member possesses an energy equal to the energies of the same constituents, less 230,000 calories, which number gives the heat of formation of the zinc sulphate from its elements. Now the difference of these two numbers, 230,000—123,000, corresponds exactly with the 107,000 calories set free in the reaction of the acid on the zinc. Here are, therefore, three numbers which can be obtained by independent measurement, and between which exists a necessary relation; thus the calorimetric study of chemical reactions enables us to establish relations between different quantities of heat and in particular to calculate one of them, if the others are known.

We can now conceive the possibility of determining experimentally the heat of formation of all compounds, and hence of knowing beforehand the thermic effect of any reaction

by which these bodies are transformed into each other. These tables of thermo-chemical data exist; they were drawn up by Berthelot from his own innumerable experiments and those of his pupils. The question now arises as to the use to be made of them.

The scientific value of a collection of numbers depends on its usefulness for formulating laws or for predicting new facts. Thus no science has accumulated such quantities of numerical data as meteorology; but as long as nothing was deducted from them all we had the right to refuse to regard meteorology as a true science. If thermo-chemistry is nothing but a collection of numerical constants it deserves the same severe treatment. Now, according to Thomsen and Berthelot, the data of thermo-chemistry ought to allow the prediction of what reactions are possible and what reactions are impossible. They permit us to do so by means of the *principle of maximum work.*

Let us consider a stone placed on the declivity of a hill; the slightest shock may cause it to fall. As it falls, its energy, that is to say its capacity for doing work, decreases by the

amount of work required to restore it to its original level; it will continue falling until, sooner or later, some obstacle arrests it, and then its stability will be great in proportion to its proximity to the bottom of the ravine, that is to say, to the portion of its energy expended.

The thermo-chemists took this analogy for their starting-point; they compared a system of bodies in reaction to a falling stone and concluded that the direction of the transformation must always be of a nature to cause loss of energy in the system—that is to say, it must release heat; and the most stable transformation, the one most likely to occur, will be the transformation which causes the release of the greatest possible quantity of heat. This principle, which owed its origin to Thomsen, received at the hands of Berthelot all the development necessary to determine its meaning and its consequences. This very precision, however, enables us to subject it to severe criticism.

One may remark, first of all, that the application of the principles of thermo-chemistry is meaningless unless all the conditions of the problems are carefully defined; the amount

of energy liberated varies with the temperature, the pressure and the physical state of the reacting bodies; hence the application of the principle of maximum energy demands a greater number of numerical data than are usually available. But this is not a serious obstacle, as it is possible to fill gaps of this nature. What, however, is more momentous is that the principle itself of maximum work is inaccurate.

One might have suspected as much from the simple fact that some chemical reactions are accompanied by an absorption instead of a release of heat. If, for example, we mix alcohol and acetic acid and keep the temperature of the mixture at 100° C., in a few hours' time a perceptible portion of the mixture will have been converted into acetic ether, while the reaction, instead of releasing heat, will be found to have absorbed it, that is like (to take our original comparison), a stone which, of its own accord, rolls uphill. Chemistry is full of similar instances. However, the chemists did not surrender; this is a typical case, because it illustrates the persistent and injurious tendency of each science to separate from the other

sciences, and of all men, even the greatest scientists, to form castes. So the chemists pretended that the principle of maximum work remained valid provided that one took into account in a reaction only energy of an exclusively chemical nature, and excluded, as foreign, all manifestations of energy attributable to external or physical causes.

This type of argument involves the erection of a watertight partition between chemistry and physics, but Nature knows no such absolute boundaries; phenomena form a whole which cannot be divided to suit our taste. Of what nature are solutions, fusions, polymeric transformations? Are they physical or chemical? We are absolutely unable to tell. How is a foreign energy introduced into the just-mentioned mixture of alcohol and acetic acid by keeping its temperature at 100° C.? In what way does this differ from keeping it at the ordinary temperature, or at any other temperature? Moreover, and this is a characteristic example, what right have we to pretend that when the electric current decomposes sulphate of zinc in a voltameter it is acting as physical

energy, whereas in a cell the same current, produced by the action of the sulphuric acid on the zinc, becomes the residual energy of the reaction, a purely chemical form of energy. It is therefore necessary to abandon all these subtle distinctions, which correspond neither to any theoretical reason, nor any practical criterion.

When we have once thoroughly grasped the impossibility of separating chemical and physical effects, the study of our facts teaches us that the law of phenomena is more complex than would appear from the principle of maximum work. The comparison of a system in reaction to a falling stone is too simple, the truth is more complicated, and its revelation is a task for the science of energy, the thermo-dynamics of Mayer, Carnot and Clausius.

This undertaking was first accomplished by one of the greatest physicists of modern times, by Helmholtz, and completed by Gibbs and Duhem. The following comparison is taken from Duhem, an acknowledged master of modern physics:

"The present data of experimental thermo-

chemistry resemble a sketch map drawn by the first explorers of a mountain range; the principal peaks are already put down with their approximate dimensions. Thus we know, more or less exactly the quantities of heat brought into play by the principal physical or chemical modifications, when they take place under more or less clearly determined conditions, but we cannot follow the undulations of the chain between the peaks; what is wanting is what geographers call the relief of the country.

"The quantity of heat called into play by a given reaction or transformation varies with all the circumstances surrounding the reaction or the transformation, such as the temperature, the pressure, the greater or less dilution of the reacting bodies; thermo-dynamics requires to know, for all the important reactions of chemistry, the expression of the heat of reaction as a function of all these variables; it demands from the thermo-chemist, who is studying a reaction, not a single experiment, but a detailed and frequently exhaustive monograph."[1]

[1] "Thermochimie" *Revue des questions scientifiques*, vol. xii., 1897, p. 361.

Thus the intervention of physics has enabled us to bring things to a focus: the principle of maximum work would be rigorously true only at the absolute zero of temperature, that is to say at 273° below zéro centigrade. Except in this extreme case the direction of reactions is not determined by the total energy, such as is given by thermo-chemical tables, but by a part of this energy, called by Helmholtz the *free energy*, whose expression is known and which can be determined.

The path opened by Thomsen and Berthelot, following Bergmann, has now been marked out along its entire length. We know where it can lead and we know the efforts required from those who traverse it. But, at the same time, we see that the short cut offered by the principle of maximum work was only a false trail; the right road is much longer and harder, but it leads to scientific truth.

There is another way of studying chemical reactions; instead of viewing the battle from afar and judging its course by the smoke and the sound of the cannon, we may penetrate

into the thick of the fight, count the combatants, follow their hand-to-hand struggle and judge the result on the ground. The honour of this new method belongs to Berthollet.

When sulphuric acid is poured into a solution of potassium nitrate no visible phenomenon is manifested, and many people might say that the two liquids have mixed without any chemical reaction. Berthollet saw that a reaction does take place, and that in reality the base is divided between the two acids, so that the liquid now contains four bodies: potassium nitrate, potassium sulphate, sulphuric acid and nitric acid; a state of equilibrium has been established between these bodies, capable of persisting indefinitely.

Now supposing something happens to eliminate one of the four antagonists, the equilibrium will be destroyed, then re-established by a new chemical transformation, and the reaction will advance accordingly step by step. If, for example, the mixture is warmed, the nitric acid, being more volatile than its competitors, will escape; then the influence of the sulphuric acid, being no longer held in check, will deter-

mine the formation of a new quantity of potassium sulphate and of free nitric acid, the latter will evaporate, and the process will thus continue until all the nitric acid has been eliminated and nothing remains in the liquid except potassium sulphate and sulphuric acid, if an excess of the latter was originally present.

This example, one of a thousand, sums up the doctrine of Berthollet. It presented, at least, the advantage of great practical interest as it enables us to foretell, with practical certainty, the course of reactions, according to the insolubility or volatility of one of their possible products; it explains, for example, why calcium sulphate and ammonium carbonate produce, by their reaction when cold, insoluble calcium carbonate and ammonium sulphate, whereas when hot the inverse reaction takes place, in consequence of the volatility of the ammonium carbonate. But the high priests of classical chemistry continued for years to regard Berthollet's laws as beneath their contempt, calling them empirical rules. No qualification could have been less justified, because Berthollet saw in these rules, and we are to-day compelled

to do likewise, the first sound ideas concerning reactions. Berthollet was the first to understand the meaning of chemical equilibrium, and in a particular case he saw how this equilibrium could be destroyed and lead to a complete reaction.

These remarkably philosophical ideas of Berthollet had long to wait for their logical development at the hands of Henri Sainte-Claire Deville. It was in the laboratory of the Ecole Normale, quite near the one where Pasteur discovered a new world, that Deville established, by indisputable and repeated experiment, the laws of dissociation. When chalk or carbonate of lime is heated in a closed vessel it decomposes into lime and carbonic-acid gas until this gas reaches in the receptacle a pressure which depends on the temperature and on it alone; it is called the *tension of dissociation.*

If part of the carbonic-acid gas is removed more is formed by decomposition of the carbonate; if, instead, more gas is introduced into the receptacle it combines with the free lime until the tension of dissociation has been restored. Thus, in compliance with Berthollet's views,

the volatility of the carbonic-acid gas is actually the determining cause of the reaction. But now we are dealing with experiments and not with hypotheses, and these experiments actually show us a state of equilibrium capable of being upset in either direction; and the sign $=$, which in the old chemical equation expressed solely the conservation of the masses in the reaction,

$$CaCO_3 = CaO + CO_2$$

assumes henceforth a new and more striking meaning; it indicates the equilibrium of opposing forces.

We should now understand why chemistry owes so much to the study of these states of equilibrium, and of these reactions which can take place either in one direction or in the other, and which are called *reversible* reactions; it is because in every science a knowledge of statics precedes and facilitates the knowledge of dynamics. When we witness one of these reactions which attract our attention by their violence, such as the attack of zinc by sulphuric acid, we can only note the phenomenon, but are incapable of causing it to alter its course; now it is only by methodical experiment that scien-

tific knowledge can be discovered. If, however, violent reactions are unsuited for experiment, it is quite different with slow and weak reactions, and especially with these reversible reactions which occur on the border of states of equilibrium. The chemist can then bring into action, separately, each of the variables defining the system: the masses of the bodies under consideration, their degree of dilution and temperature, the duration of the reaction, and he can determine the direction and the magnitude of the resulting action. Thus, whereas the early chemists were attracted by the intensity of violent reactions, modern chemistry is chiefly interested in slow reactions, in which it is easier to take the mechanism to pieces and expose the springs to view. The great chemist, J. B. Dumas, expressed this idea with the prescience of genius when he wrote:[1] "We may predict that if some day accurate views are obtained regarding the nature of chemical affinity they will be due far more probably to the study of the weakest than of the most energetic chemical actions."

[1] *Leçons de Philosophie chimique*, delivered at the Collège de France in 1836, p. 195.

The direction which Deville imparted to chemical research has proved every day more fruitful. During some twenty years the French school, which had shown the road, distinguished itself by its industry and zeal. Berthelot himself, before being attracted to the thermo-chemical researches, which he thought more fruitful, had made his contributions to the new ideas regarding states of chemical equilibrium by pointing out the part played by them in the formation of ethers by the action of acids on alcohols. Then little by little this flame of enthusiasm died down in France to be rekindled elsewhere, chiefly in Holland, Germany and America, by the labours of Van t'Hoff, Hortsmann and Gibbs.

The causes of this transference of scientific interest are fortunately only too clear. The great French chemists of the end of the nineteenth century were too exclusively chemists; they placed too much confidence in the reliability of their methods, and the memory of the lucubrations of the alchemists made them distrust the abstractions and generalisations of mathematical physics. Thus, after having set

forth with perfect clearness the terms and the elements of the problem, they were compelled to stop half way; the problem now required the application of methods which thermodynamics had already employed and tested in the study of purely physical states of equilibrium. Hence, while French science was delayed by other researches, physico-chemical laboratories were being opened at Amsterdam, Leyden, Gottingen, Leipzig, Berlin and Ithaca, with the object of developing theoretically and practically chemical mechanics. To-day, thanks to these efforts, the laws of chemical equilibrium are known at least in part. Chemical dynamics is, however, barely sketched out, and is limited at present to a simple classification of the reactions observed when the temperature and pressure of a system are varied; one exception deserves to be made in favour of explosive reactions. The necessary study of explosives has contributed to chemistry by accumulating much work on this subject; the important part taken by MM. Vieille and Berthelot in these studies is well known.

In consequence of all this progress chemistry is suffering from growing pains. It no longer knows the limits of its domain; the barriers which separated it from the other sciences have fallen one after the other, and in their place are growing and prospering other branches of universal science:—physiological chemistry, which devotes itself to disentangling the reactions of living matter; chemical mineralogy and geology, which summon the resources of the laboratory to explain the origin of minerals and formations; and finally physical chemistry, which endeavours to solve the fundamental problem of chemistry, the study of chemical reactions, by bringing to bear on it all the theoretical and practical resources of physics.

While chemistry sees its limits disappearing, it is undergoing an internal evolution and steadily increasing the intimacy of its union with physics. Formerly it was possible to distinguish a chemical laboratory from a physical laboratory on the threshold simply by the smell; this distinction is becoming every day more difficult. It has been said that Lavoisier founded chemistry by giving it the balance;

it might be added that every forward step made by this science is connected with the introduction of some new physical apparatus: the calorimeter and the thermometer identified with Lavoisier, Berthelot, Raoult; the manometer with Gay-Lussac and Sainte-Claire Deville; the electric current with Davy and Moissan; the spectroscope with Kirchhoff and Bunsen; the polarimeter with Biot and Faraday; the electroscope with Curie.

With its growth chemistry has lost its object, because to-day nobody can define, with accuracy, the purpose of its researches. It no longer places that purpose in the study of chemical species; it is now the business of physics or mineralogy to tell us that chlorine is a liquifiable gas, or that sulphur is an octahedral crystal. And if, to be more logical, we define chemistry as the study of reactions, we find it impossible to tell where the reaction finishes and the physical phenomenon commences. If it be said that the former involves permanent change, while the latter does not, the magnetisation of steel would forthwith become a chemical phenomenon, because it survives the cause

which determined it. The first is also said to cause molecular modification, whereas the second leaves the molecule intact; this view is equally risky, because it would place under the heading of chemistry the modifications of the physical state of water and its anomalies near its point of maximum density. It is thus really impossible to discover an accurate definition at the present day.

To sum up, chemistry sees its fundamental laws losing their character of absolute necessity and rigorous exactitude. The belief in the existence of simple bodies not transmutable into each other, the law of the conservation of matter and the law of simple ratios, formed the foundations of the structure erected by Lavoisier and his successors. We have seen that for us the last of these laws has lost its originally imperative character. The law of the conservation of matter has, in its turn, been the object of attacks, regarding which it is difficult to form an opinion. Landolt, after weighing with the most minute precautions chemical systems before and after reactions, thought he noticed a systematic variation of

weight of the order of millionths. Our views have, however, been shaken chiefly by the experiments of Curie and Ramsay; the multiplicity of radio-active bodies and of their metamorphoses, the transformation of radium, a well-defined element, into helium, another element, and finally the other transformations carried out by Ramsay, suggest that we may not have reached the end of our surprises.

But does it follow that because modern chemistry can no longer define its purpose, its means, or its principles, it has disappeared from the number of the sciences? Far from it. Every science at its beginnings naturally attains, by rough means, simple results, which form the inducement to more complete investigation. The astronomy of Kepler and Newton was more simple than the astronomy of to-day, but the object of science is not simplicity.

Nature requires science to be one like herself; she denies us the right to pour our knowledge into separate vessels. The evolution we are witnessing is therefore logical and necessary, but the infirmity of our minds compels us, notwithstanding, to retain classifications: but

the present classifications are bad. It is a reasonable conclusion that the science of the future, though daily approaching unity, will be susceptible of division into three broad groups: sciences of the ether, sciences of inanimate matter, and sciences of life.

Hence chemistry, mechanics, and part of our present physics appear destined to combine in one great synthesis. This new grouping of the sciences will doubtlessly reveal in due course harmonies now unsuspected.

TRANSMUTATION AND THE EXPERIMENTS OF RAMSAY

THE word transmutation evokes in our mind the speculations of the alchemists, the philosopher's stone, Raymond Lully's *quinta essentia*, the alcahest of Paracelsus, and all the mysterious elixirs which the triumphant reason of modern times thinks it can condemn beyond appeal. For this reason the pursuit of transmutation appears to many minds, opposed to inconsequent dreaming, as vain as the quest of perpetual motion or of the squaring of the circle. But a distinction must be drawn! If the mathematician has the right to say "never," the physicist and the chemist must be satisfied with less absolute and less ambitious formulæ if they desire to avoid unpleasant contradictions from experience. A few years ago the question of the unity of matter and of the transformation of one element into another was one which no one would dare to raise. And yet it has for some time been

thrusting itself forward so insistently that it can no longer be ignored, but forces us to realise that a revolution is at hand in our chemical doctrines, just at the moment when they seemed more firmly established than ever.

Fontenelle was in the habit of saying: "When a theory seems probable you may be sure that it is false!" This is not a mere sally of a disabused theorist; the truth regarding the outside world is reached by successive steps, and as each one is surmounted the aspect of the universe becomes enlarged and modified. To-day the great English chemist, Sir William Ramsay, leads us up to a new level, and we must strive to understand how the new panorama is a development and a continuation of the one to which we were accustomed.

Before thinking of transmuting bodies, it is necessary first of all to provide each of them with a distinctive docket, enabling it to be recognised by indisputable characteristics; this is exactly what was wanting to make the work of the alchemists of real use. For them everything heavy, bright and yellow was gold; this explains all their confusions. The great effort of modern

chemistry has enabled an exact description of each body to be provided; this task, which has demanded endless work, is similar to that by which naturalists succeeded in distinguishing and classifying species. It was necessary to sort out in the crowd of characteristics those which were merely accessory: colour, brightness, density, form, so full of importance in the eyes of the older chemist, were recognised to be far from characteristic; if we were guided by them, imagine how many species there would be of carbon, sulphur, selenium and phosphorus. The indisputable criterion, the mark of authenticity of each chemical species, had to be found in chemical reaction; we call *carbon* any body which, combined with oxygen, produces exclusively carbonic acid gas. Thus we are on solid ground. In default of this spectrum analysis supplies a criterion of fundamental importance. Every element when rendered luminous by an electric discharge is characterised by the emission of bright rays, whose position in the spectrum enable us to recognise and differentiate it; the exquisite delicacy of this criterion renders it especially valu-

able. In his recent researches Ramsay worked with tiny Geissler tubes containing four cubic millimetres of gas, and could reveal traces of elements whose total weight did certainly not exceed one ten thousandth of a milligramme.

The systematic study of reactions, while supplying the means of characterising chemical species, enables them to be classified in two groups: bodies which can be obtained by synthetic reactions, or which can be separated into several others by analytical reactions, are called compound bodies; and bodies which so far have resisted all effort to split them are considered for the present simple bodies or elements. This conclusion, justified by thousands of experiments, is however only provisional, and it is advisable always to remember the weighty words of Lavoisier:

"If we attach to the name of elements or principles the idea of the final term attainable by analysis, all the substances which we have hitherto been unable to decompose by any means are for us elements; not because we can be sure that these bodies, which we consider simple, are not actually composed of two or even more principles, but because these principles never

separate, or rather, since we have no means of separating them, they act, so far as we are concerned, as elements, and we must only assume them to be compound when experiment and observation have supplied the necessary proof."

We are thus led to consider compounds as formed by the association of a certain number of elements which they contain. We are here leaving the domain of facts for a hypothesis which has been disputed by prominent chemists, and among others by Ostwald: that oxide of iron can always be decomposed into oxygen and iron, and can be obtained by the combination of these elements, is an incontrovertible fact, but that the oxide of iron actually contains oxygen and iron is not at all certain. A circular motion may be decomposed into two oscillating motions along two diameters of the circumference, and may be produced by the superposition of these two movements, and yet not actually contain either.

As a matter of fact all chemists implicitly admit this hypothesis, that the millions of bodies now known are derived from the association of seventy-two different elements, which cannot be

transformed one into the other; such is the aspect under which the world of matter appears to us.

The firm adherence of chemists to this doctrine, and their entire reluctance to discard it for some adventurous speculation, is thoroughly justified; as a matter of fact, although in the light of recent discoveries the indestructibility of the elements has ceased to be an indisputable truth, it still preserves the character of a practical truth. Chemists, or at least those who take the trouble to think, have, however, never regarded the existence of seventy-two elements as an infallible dogma. This number is certainly not fixed for all time, as hardly a year passes without the discovery, fancied or real, of some new element. Everyone will still remember the startling discovery made some few years ago by Lord Rayleigh and Sir W. Ramsay of a series of elementary gases—*helium*, *neon*, *argon*, *krypton* and *xenon*; that is to say, five elements contained in the air which we breathe and which we thought we knew so well.

The number of the bodies classed as elements is continually increasing. There is something strange in this, and our inner sense protests

against the existence of so great a number of irreducible elements. We have a confused feeling that this complexity must hide a simpler truth. However, we no longer believe, like the men of the eighteenth century, that true laws are necessarily simple. We have too many proofs of the complexity of Nature, and we think we know that this complexity is produced, not by the juxtaposition, but by the combination of a small number of elements. In this manner organic chemistry is being constructed out of only four elements, and the complicated motions of the stars obey the single law of universal gravitation. This is doubtlessly why the hypothesis of a single primordial matter lurks in the depths of so many minds; at the slightest occasion it bursts out like a smouldering fire. The following are two topical examples.

In 1815 the English chemist, Prout, expressed the view that the atomic weights of all elements must be multiples of the atomic weight of hydrogen. This assertion, unsupported by proof, had been forgotten when, thirty years later, Jean-Baptiste Dumas, the great chemist, who was able to take such broad and philo-

sophical views of science, took it up again and supported it by many experiments; he thought himself justified in asserting that if the atom of hydrogen is taken as unity the atoms of carbon, nitrogen, oxygen and sulphur would weigh exactly 12, 14, 16 and 32. How could such a result be explained except on the assumption that the elements are successive states of condensation of a single primitive matter, perhaps of hydrogen itself? However, reality has once more destroyed hypothesis; the development of the resources of chemical analysis has permitted a more accurate determination of atomic weights, and the numbers given by Dumas have had to be replaced by more complex numbers, 11.97, 14.01, 15.88, 31.98, so that the simplicity just sighted vanishes, and with it the possibility of founding on determinations of this kind any argument for or against the unity of matter.

The identical solicitude reappears in connection with another order of considerations. The chemical species, as we know them, are far from being fixed; they seem capable, like living species, of departing in greater or less degree from a mean type. For each of these variations the physical

constants, such as colour, density, solubility in solvents, co-efficients of expansion and of elasticity, specific heat are variable; sometimes even their chemical properties are modified. Thus, ozone differs distinctly from oxygen; carbon, sulphur, selenium, and phosphorus can exist under very different forms with very different properties. This variability of species is of a nature to suggest the idea of a chemical evolution analogous to biological evolution. It is of course possible to attribute these varieties to different states of molecular aggregation; the molecule of ozone might contain three atoms, whereas the molecule of oxygen contains only two; this would protect provisionally, and thanks to a plausible hypothesis, the individuality of the elements. But there are other cases in which this kind of argument does not apply.

Let us consider for example the oxides whose metals form what are usually called the *rare earths*. These bodies were, in fact, rare and imperfectly known until the increased efforts to obtain them due to the requirements of modern industry showed their relative abundance and in any case their wide dissemination in the

earth's-crust. From these bodies have been extracted a considerable, and even yet an undetermined number of metals: *thorium*, *cerium*, *lanthanium*, *didymium*, *yttrium*. In 1842 Mosander demonstrated that the last of these metals consists in reality of three distinct bodies, *yttrium* proper, *terbium* and *erbium*; since then the unremitting work of numerous chemists has further extracted from the same bodies the new elements, *scandium*, *ytterbium*, *holmium*, *gadolinium*, to which should perhaps be added *thulium*, *neo-erbium*, *neo-holmium*, *dysprosium*.[1] All these bodies, whose properties are so nearly identical that their separation is barely possible, come to lengthen the already long list of elements. This remarkable similarity, and their association in the same minerals, suggests the inference of a common origin; this consideration led the physicist, Crookes, to his celebrated theory of meta-elements.

Crookes attributes the evolution of the various elements to the progressive condensation of a single primitive matter, but the cooling of

[1] Quite recently M. Urbain succeeded in splitting ytterbium into two elements—neo-ytterbium and lutecium.

this primitive matter having at a certain moment proceeded too rapidly, a series of incompletely-developed elements was produced, just as if Nature had been prematurely delivered and space peopled with abortions approximating to, but distinct from, normal forms. According to this *holmium*, *erbium*, *gadolinium* and *dysprosium* would be only the meta-elements of *yttrium*, and each of the known elements might, if we were skilful enough to effect the chemical separations, supply a whole series of satellites.

Even if we neglect these rare elements, whose identity is still somewhat doubtful, it is impossible to avoid being struck by the profound analogy of certain elements. Long ago Dumas, interpreting these analogies, grouped in one natural family fluorine, chlorine, bromine, iodine, and in another sulphur, selenium and tellurium. Similar natural associations unite the inert gases of the air, which we have already enumerated, the alkaline metals, the metals of the iron group. The value of these analogies, and the existence of a connection and a necessary interdependence between the elements of the same family is recognised by every chemist.

The Russian chemist Mendeléeff had the good fortune to present this interdependence in a striking form, which has for a long time compelled the attention of chemists, and will receive a fresh lease of interest from Ramsay's discoveries. If the simple bodies are arranged in the order of their increasing atomic weights, as in the appended table, the properties of the successive elements are found to present a certain periodicity. The table is divided into rows and columns so as to show this periodicity, and the arrangement is such that the columns correspond practically to the natural families already distinguished by chemists. It is true that recourse has been had to the artifice of leaving some of the squares empty, but these gaps may be assumed to correspond to still unknown bodies. In fact the bodies discovered since the publication of Mendeléeff's table have fitted as a matter of course into the empty squares; this occurred in the case of germanium, isolated by Winckler, and of gallium, obtained by Lecoq de Boisbaudran; the inert gases of the atmosphere likewise found a place waiting for them in the table. The work of Mendeléeff is open to many

and just criticisms, but chemists, almost without exception, look upon it as the screen on which the more general properties of matter group themselves; it gives a precise form, too precise and simple, perhaps, to the indisputable interdependence of all the elements.

Modern chemistry, as we have seen, while admitting the conception of elements, noted among them correlations, which suggested the possibility of transmutations; but the means at its disposal were insufficient to realise this.[1]

The discovery of the radio-active bodies supplied the necessary lever. These bodies, *uranium*, *thorium*, *radium*, *actinium*, are a marvellous and to all appearance inexhaustible source of energy. Radium in particular, the best known of all, emits incessantly light, heat and three kinds of radiation, which have been designated by the letters, α, β, γ. The α rays, according to Rutherford, are formed by molecules of *helium*, a gas four times denser than hydrogen, with a positive electric charge, and animated with a moderate speed.

[1] In 1900, Fittica, Professor at the University of Marburg, thought he had succeeded in transforming phosphorus into arsenic. But like all those of his predecessors his attempt ultimately failed.

MENDELÉEFF'S TABLE

Hydrogen 1	Helium 4	Lithium 7	Glucinium 9.3	Boron 11	Carbon 12	Nitrogen 14	Oxygen 16	....	....	....	....
Fluorine 19	Neon 20	Sodium 23	Magnesium 24	Aluminium 27.5	Silicon 28	Phosphorus 31	Sulphur 32	....	....	....	....
Chlorine 35.5	Argon 40	Potassium 39.1	Calcium 40	Scandium 44	Titanium 48	Vanadium 51.3	Chromium 52.4	Manganese 55.2	Iron 55.9	Cobalt 58.6	Nickel 58.7
....	....	Copper 63.5	Zinc 65	Gallium 68	Germanium 71	Arsenic 75	Selenium 78	....	....	....	....
Bromine 80	Krypton 82	Rubidium 85.4	Strontium 87.3	Yttrium 89.6	Zirconium 90	Niobium 94	Molybdenum 95.8	....	Ruthenium 103.5	Rhodium 104.1	Palladium 105.2
....	....	Silver 107.9	Cadmium 112	Indium 113	Tin 118	Antimony 120	Tellurium 126.3	....	....	....	....
Iodine 126.6	Xenon 128	Cæsium 132.6	Barium 137	Cerium 137	Lanthanium 139	Didymium 147	....	....	....	....	....
....	....	....	....	Erbium 170.6	Ytterbium 173	Tantalum 182	....	....	Osmium 190	Iridium 192	Platinum 194
....	....	Gold 197	Mercury 200	Thallium 204	Lead 206.9	Bismuth 210	....	....	....	....	....
....	Emanation 215	....	Radium 225	....	Thorium 233.9	....	Uranium 240	....	....	....	....

The β-rays form the trajectory of projectiles eight thousand times lighter than the preceding ones charged with negative electricity, and shot off at a tremendous speed, between one hundred and three hundred thousand kilometres per second, these projectiles being called corpuscles or electrons. Finally the γ rays, analogous to the X rays, are constituted beyond doubt in the same manner as the X-rays, by perturbations of the ether without any transference of material masses or electric charges.

But these are not the only things that are emitted by radio-active bodies; in the vicinity of a specimen of radium bodies of all descriptions, iron, indiarubber, wood, become active, that is to say, emit all the rays we have described; but their radio-activity, instead of being permanent, decreases little by little until it becomes imperceptible in the course of a few minutes or days as the case may be. The discoverers of this phenomenon, M. and Mme. Curie, named it *induced radio-activity*. This new form of energy, produced by radium, is not radiated out like the preceding ones; it appears rather to diffuse like a gas, emanating from the radium and spreading

into the surrounding space, impregnating the bodies it encounters and transferring to them the activity derived from the radium.

This explanation of induced radio-activity, advanced by Rutherford, ceased to be a hypothesis on the day that Ramsay and Soddy managed to collect the "emanation" of radium and to isolate and study it. The emanation is a true gas which follows Boyle's law and liquifies when cooled in contact with liquid air; it is characterised by a bright spectrum, which recalls that of the gases of the *argon* series; on the other hand its chemical inactivity appears absolute, in fact, it may be heated without any alteration in contact with the most energetic oxidisers and reducers; for this reason Ramsay considers it a simple gas, with atomic weight about 215, and occupying in the periodic classification a place below xenon.

Here we have a fact which has no analogy in chemistry. Radium, a body accurately defined as an element by its spectrum and all its chemical properties, decomposes spontaneously into another body, which appears also to be simple, and if the rate of transformation ascertained

experimentally, viz., one milligramme of emanation produced per gramme of radium per year, is permanent the transformation would be complete at the end of a few thousand years.

We have not come to the end of the complications. Ramsay kept a few cubic millimetres of his precious emanation on mercury in a tiny test-tube, where it formed a glowing column. A few days later he noticed that the volume of the gas had decreased; the decrease continued regularly until at the end of three weeks nothing was left in the test-tube but a glowing point; at the end of a month the last trace of the emanation had disappeared; however, when the mercury was lowered, forming a vacuum in the apparatus, and the tube was slightly warmed, an amount of gas was produced equal to about four times the initial volume of the emanation; this gas was *helium.*

So unexpected a result can only be accepted by science after serious verification; in addition to Ramsay seven observers, including Curie, have pursued the question in France and Germany, and ascertained that not only radium, but also *thorium* and *actinium* are transformed, first into the emanation and finally into helium.

Moreover, these facts agree with what we know regarding the origin of helium on the earth; this gas has always been found in radio-active minerals, and its presence has been also recognised in the gases emitted by deep mineral springs, which must have been in contact underground with similar minerals.[1] We have, therefore, the following incontestable fact: radium and its congeners are elements in a state of constant disintegration; they transform spontaneously under our very eyes into the emanation which in its turn becomes helium. This evolution is predetermined and absolute; we can neither accelerate nor retard it, and still less reverse it and revert from helium to the emanation or to radium. As Ramsay has himself pointed out: "Although the analogies derived from ordinary chemistry are insufficient to represent completely these new phenomena they may help us to define our ideas; it is possible to remove the chlorine from ammonium chloride NH_4 Cl when one would obtain the group NH_4, but this group is instable even in the

[1] The spring of Bourbon-Lancy sets free yearly ten thousand litres of helium.

presence of mercury; it soon decomposes into ammonia NH_3 and hydrogen. To reconstitute the compound NH_4 Cl it is necessary to follow a much longer course; first the chlorine must be combined with the hydrogen and then the ammonia subjected to the action of hydrochloric acid; we are perfectly able to carry out these transformations, but as yet we have not been able to produce similar changes with radium and the products of its decomposition."

No agent capable of modifying the evolution of radium is known; it is, however, probable that such agents exist. The radio-active substances have lain buried in the depths of the earth for thousands of centuries, and had their transmutation been taking place at the rate observed by Ramsay they would have long ago disappeared completely. It is therefore reasonable to infer the existence of some retarding action, or even of a process of retrogression still unknown to us.

Helium is not the only product of the disintegration of radio-active bodies; an extraordinary quantity of energy is liberated at the same time of which nothing in any known chemical re-

action can give an idea. The measurements made by M. and Mme. Curie and by Rutherford show that in the process of becoming helium one cubic centimetre of emanation liberates a quantity of energy 3,600,000 times greater than is produced by the explosion of a like volume of the explosive mixture of hydrogen and oxygen. This process is, however, gradual, lasting about a month, and moreover, the energy appears not only in the form of heat, but also of light and α, β, and γ rays.

This result is of the greatest importance; it places at our disposal a new and unprecedented source of energy. It is therefore reasonable to hope that the power freed by the disintegration of radium will subject matter to profound modification, and that a body sufficiently energetic to decompose itself will prove capable of transforming all elements brought into contact with it. This was the guiding thought of Sir William Ramsay and the motive of the experiments which he has been patiently carrying out for three years, with a skill as rare as it is necessary in such researches, where only the minutest quantity of material is available and a few cubic

millimetres of gas have to be manipulated without loss for several months, requiring in the operator an extreme degree of experimental ability. We must not allow the extreme difficulty of the task to incline us to scepticism; those who have seen Ramsay in his laboratory know that no one could be better prepared for such an arduous task. They know how conscientiously and diffidently he advances on the path before him.

"During my last visit to Ramsay, over a year ago," writes the German chemist, Ostwald, "he showed me, in the private laboratory which he has had built in his house in Regent's Park, some white crystals on a small watch glass. This substance had been obtained by the action of the emanation of radium on a solution of copper sulphate. After eliminating the copper by sulphuretted hydrogen the residue left by the evaporation of the clear liquor shows distinctly in the spectroscope the line of lithium, as I was able to ascertain, thanks to Ramsay's kindness. As this fact is absolutely extraordinary Ramsay requested me not to publish it before it was perfectly confirmed. This reserve is no longer necessary, as a few days ago I received the proofs

of Ramsay's communication to the world of science. Not only have the earlier results been confirmed, but those which this skilful experimenter has obtained since then fully confirm his original hopes."

We may therefore follow Ostwald's example and have full confidence in the man who has already enriched Science by so many admirable discoveries. This is all the easier because in his latest results we find an order which our imagination could never have foreseen but which satisfies our reason.

We already know that the emanation, when isolated and pure, transforms itself spontaneously into helium. If we now enclose in a small glass phial this same emanation with a little water, during a month, the period of the transformation, the water will be seen decomposing gradually into its components, oxygen and hydrogen, but, in contrast with the previous case, very little helium is formed; what is found is chiefly *neon*, a gas belonging to the same series as helium, but whose atom is five times heavier.

If, on the other hand, we confine the emanation with a solution of copper sulphate or nitrate

neither helium nor neon is formed, but exclusively argon, a gas still heavier than either, and belonging to the same family; in addition to the unaltered copper salt the liquid is found to contain a perceptible quantity of sodium salts and very distinct traces of lithium,[1] the experiment repeated four times gave identical results, and Ramsay checked it further by treating a solution of copper nitrate in exactly the same manner, with the single exception that it had not been placed in contact with the emanation. Under these new conditions no trace of lithium was obtained, and only half the quantity of the sodium in the previous case was ascertained to be present.

The presence of sodium is a normal phenomenon; the glass of the bottles contains soda and always communicates traces of this substance to a liquid with which it has been in contact. On the other hand, nothing short of a transmutation can explain the presence of lithium. Further experiments, thrice repeated, at six months' intervals, manifest another phenomenon of the

[1] The weight of the lithium formed, estimated from the intensity of the spectrum lines observed, would be about one twenty thousandth of a milligramme.

same order; a solution of thorium nitrate left to itself in a closed vessel gives off continuously carbonic acid gas. The carbon seems to appear here as a new element. However, Ramsay is awaiting, before asserting it, the result of determinations now being carried out.

All these experiments are sure to be carefully checked. Let us therefore accept with this reservation the new facts. Mendeléeff's periodical classification enables us, according to Ramsay's views, to arrange them at least provisionally. When the emanation, which for us is a gas of the helium family, is left to itself its atom, which is heavy and charged with energy. bursts like a bomb and is reduced to its elements. From it helium is formed, the first term of the series. If, on the contrary, the emanation is placed in contact with other bodies, part of its energy of disintegration is applied to them; in contact with water the emanation splits into larger particles than before, and the second term of the series, neon, is obtained. If, finally, the emanation is placed in contact with a copper salt the copper is reduced to one of the less heavy forms of its own group, that is to say, to lithium,

perhaps at the same time to sodium, while the emanation, receiving an even smaller impulse than in the last case, can be degraded only to the state of argon. Possibly the carbon resulted, by some analogous process, from the disintegration of thorium, an element of the same family, but of twenty times greater atomic weight.

We may hence say that the α, β and γ rays, this powerful artillery of the radio-active substances, act on so-called elements like shells on an armour plate. The energy expends itself on the shell as well as on the obstacle, with the result that in proportion as the damage to the plate is great the shell suffers little injury.

Such an argument, as Ramsay himself admits, can only be considered as a first and very rough approximation, but it is the only general idea which at present embraces the new facts. One thing, however, is certain. Our present idea of elements is being profoundly modified. We are certain that transmutation is no fable, because we have seen helium being born under our very eyes, and we have very strong reasons for believing that other elements equally well defined—neon, argon and lithium—can also come into

existence through atomic disintegration. However, we have hitherto succeeded in influencing the elements only in one direction, passing from the heavier to the lighter atoms. It has always been easier to demolish than to rebuild, and knowing the tremendous display of energy required for demolishing we may fancy what will be required for reversing the process, for making, let us say, gold out of copper.

It is a remarkable fact that the heaviest elements should be also the most unstable (the only ones which disintegrate spontaneously occupy the last line of Mendeléeff's table), and that the others decompose invariably into lighter bodies than themselves. Classical chemistry had already accustomed us to this notion, that the more complex compounds, whose molecules are precisely the heaviest, are, at the same time, the most unstable; those which are present in living beings, and are extremely complicated, seem even incapable of existing in a state of equilibrium; they are so intimately associated with life that they evolve with it continually. Thus a chemistry of the elements seems to be growing up on the model of the

classical chemistry of compounds. The atom is no longer the last term; chemists, following physicists, are compelled to dissociate it, and are in their turn wondering what game Nature is playing by giving us so many reasons for believing in the discontinuity of matter and so many for doubting it.

DOES MATTER EXIST?

We believe in the existence of matter automatically and instinctively, on the concordant evidence of all our senses. But philosophers and scientists have taught us for ages that our senses are frequently false witnesses; the art of the conjurer and of the showman prove this to us every day. And, as a matter of fact, we would be extremely puzzled to say what this matter is in which we so firmly believe. It appears to us, like Proteus, under a thousand different forms. What are the qualities which define it, which form its true essence? A question frequently debated but not easy to answer.

For many impenetrability is the very essence of matter. Classical teaching has asserted and repeated again that two bodies cannot at the same time occupy the same place in space, as if it were an evident and experimentally-ascertained fact, but nothing is less certain. Oxygen and nitrogen are confounded in the air which we

breathe, water and alcohol in the wine which we drink, so that we are incapable, by any logical or experimental process, of defining a volume, be it ever so small, which will contain oxygen without nitrogen, or water without alcohol. On the other hand, we can realise a space entirely void of matter and yet practically impenetrable. Let us imagine a powerful electro-magnet, with its two iron poles placed a few centimetres apart. Let us take a sword of the best and sharpest steel and try to cleave this space, this field. We could not succeed had we the strength of Samson, and it is not the small quantity of air between the poles that prevents us; we might remove it all, and yet that field would remain equally impenetrable to our sword. Better abandon as beyond reason and experiment this ancient notion of impenetrability, which is merely an heirloom of Cartesian metaphysics and encumbers our brains to no purpose.

Let us also neglect all the properties of matter which are not general or essential, in order to attain our object. The different sciences, mathematics,. physics and chemistry, are agreed in characterising matter by three fundamental pro-

perties. All matter has mass, is heavy and is inert.[1] It is a remarkable fact that scientists belonging to different centuries and having such diverse training should unite in this common affirmative. If any object, such as a piece of chalk, is put in one of the scales of a balance, a certain weight, say 20 grammes, placed in the opposite scale will balance it; hence the inference that the piece of chalk contains as much matter as the 20 grammes of copper, though it may not be the same kind of matter, and the mass of the chalk is said to be 20 grammes. Whether it be gold, platinum or hydrogen, the lightest of gases, it can be put in the balance and the quantity of matter it contains measured. Here we have therefore a property common to all kinds of matter, the possession of mass, and this property is characteristic because if the operation is repeated at the pole, at the equator,

[1] It is interesting to remark that regarding this question of the essence of matter the ideas of scientists and metaphysicians have evolved on parallel lines. The hypotheses of Descartes, which proclaim extension to be the fundamental property of bodies, have given place to Leibnitz's conception of a world based on the existence of force; now the notion of force is as closely associated with the notion of mass and inertia as the idea of extension is with the idea of impenetrability.

or even in the interior of the earth, or on the moon, the same mass will invariably be found for the same object. If the object is hot or cold not the slightest difference will be found in its weight, however accurate the measurement may be; consequently heat is something immaterial, because its addition to matter leaves the mass unchanged; the object in the same way may be electrified without modifying its weight, hence electricity also is not material.

Here we have at last the sovereign criterion enabling us to define matter, to trace it everywhere, and if we complete our idea by combining with it the notion introduced into science by Lavoisier we shall conclude that matter is indestructible and imperishable, and that it constitutes the primordial and perhaps the sole element of the world. Here stands the citadel. It is here that we must strike if we are to overthrow the materialistic conception of the universe, but there remain some outworks to be demolished before the final assault.

Let us leave for a moment the question of mass and turn our attention to the meaning of

weight and inertia. All matter, we are told, is heavy. Now the piece of chalk which we mentioned above would lose its weight if it were taken to the centre of the earth, and the same would happen if it were placed at a suitable distance between the earth and the moon, or the earth and the sun; would it then cease to be matter? Here is something to give one pause, but what is more serious still, a profound mystery cloaks everything connected with weight. What is weight? We are in absolute ignorance regarding it. We know that a stone falls, we do not know why it falls. The existence of forces hooked on like springs between all material bodies is a childish hypothesis. Though we do not know the true nature of weight, we feel confusedly that it does not dwell within the heavy bodies, but outside them; in other words, that it is the result of a pressure exerted on bodies by the immaterial medium, which has been named ether, and to which we shall return later.

We are also in the habit of saying, on the strength of official science, that matter is inert and that this is one of its characteristic properties.

This belief in inertia is the result of superficial observation. It is true that our piece of chalk will remain on the table, when once placed there, until some other moving body, say a hand, comes into contact with it, and that once thrown into space it will continue its motion after the propelling agent has ceased to act. It is again inertia which compels the mass of the pendulum to reascend the second part of its trajectory. Likewise, if we open suddenly the tap of a water-pipe the liquid does not immediately reach its normal speed, and if we shut the tap just as suddenly, the liquid, carried ahead by its own movement, will strike against and perhaps break the pipe; this is the water hammer familiar to students of hydraulics. All these actions are co-ordinated and explained ingeniously by the principles of mechanics founded on the existence of forces and on the inertia of matter. We may be sure that these ideas, on which the human mind has rested for centuries, are far from being valueless, and do not deserve our disdain, but we must not allow the force of habit to transform simple hypotheses into indisputable principles. We must rather recognise that the world

which we know is beginning to be too vast and too complicated for them. Inertia to-day holds its place in our belief thanks only to mental indolence, and to the absence of a co-ordinated system of more appropriate hypotheses.

Those who believe in the inertia of matter as in a scientific dogma would do well to study the Brownian movement, by observing through a powerful microscope a small quantity of Chinese ink diluted with water; they will see in the field of the instrument solid grains in incessant motion, hurrying to and fro, spinning round like dervishes, then stopping, only to start again; this goes on for years, and our observations show that it may continue for ever; as a matter of fact some crystals of quartz are known which contain a small and entirely enclosed cavity full of liquid, in which may be seen a tiny gas bubble in ceaseless agitation, and this tremor has no doubt been continuing ever since the first ages of the world, when the bubble was shut up in its quartz prison.

Moreover, all our knowledge regarding Nature confirms this view that the final elements of matter are in a state of perpetual and spontane-

ous agitation; a lamp, a hot body (and all bodies are more or less hot), emit the waves which constitute radiated light or heat. How could they do this if their elements were frozen in eternal repose? If we consider matter to be dead it is because we observe it from too great a distance, or because our eyes are not sharp enough. In the same way if we could see at a distance of ten miles an amphitheatre full of people the whole would strike us as a motionless mass. Experience, therefore, proves that matter is never at rest, and though we postulate that its movement is due to forces which we have never seen and which we can only define as the cause of this movement, that is simply a hypothesis, a hypothesis which we certainly have the right to make but which we must feel to be fragile.

Something remains to be added to all these arguments. Classical science tells us that everything possessed of inertia is matter, everything not possessing inertia is immaterial; heat is immaterial, because it is incapable of overshooting its position of equilibrium, of ascending from a cold body to a hot one after having descended from a hot body to a cold one.

But what are we to think of electricity? Electricity is not matter and yet it possesses a true inertia. When the free ends of two copper wires connected to the terminals of a cell are brought into contact a current passes over them, but it does not reach instantaneously its normal strength, it requires a certain time to do so, as if the cell had to overcome a certain inertia; and again, when the two copper wires are separated the current does not stop instantaneously, it can even force a passage across the air separating the wires and produce a spark. We cannot fail to notice the striking analogy between this phenomenon and what we were saying a moment ago about the movement of a stream of water. And yet for years we shut our eyes and disregarded this analogy; we even relegated the two phenomena to opposite extremities of the domain of science, and called them by different names in order to reduce the temptation to place them together. To-day several scientists, among others Sir Oliver Lodge, the celebrated physicist of Birmingham, have removed the mote from our eyes. They go even further and think that there is in reality no other inertia but that

of electricity, and that the inertia of matter is due to the electric charges which it bears.

All this shows clearly that our attempts to complete our original conceptions of matter have not led to precise and coherent results. But we are only at the beginning of our difficulties. Matter, even with the addition of all possible forces, is insufficient to explain many phenomena. Let us, for example, consider light. We know, beyond doubt, that between the earth, the sun and the stars there is no trace of matter except the very thin layers forming the atmosphere of these bodies, and we also know that light is merely a vibratory movement, which is propagated at the rate of 186,000 miles per second. Thus, from the moment a ray of light leaves Sirius until it reaches us eight years elapse. During this long journey over the paths of the heavens the light was no longer on the star, nor was it in our atmosphere. Where was it then? What has been vibrating? Thus our poor mind, which has to struggle with problems above its power, is compelled to imagine the ether, this medium which fills the universe and transports

by its vibrations the radiations of light, heat, electricity, and perhaps even actions at a distance, such as the attraction exercised between heavenly bodies.

I am well aware that at the mention of ether those who are not in constant contact with scientific thought cannot avoid feeling incredulous. They find it difficult to accept the reality of such a medium, which our senses cannot reach directly, and wonder whether we are not allowing ourselves to be deceived by philosophical dreaming. On the other hand scientists have, by force of habit, come to believe in ether as we believe in our own existence. This deep faith does not prove them to be in the right, but the disagreement vanishes when we take the trouble to clearly understand the value and the implications of our scientific hypotheses. It must be clearly understood that we pretend to no knowledge concerning the reality of the external world. We know only our own sensations, due either to observation or to experiment; all we attempt is therefore to form a mental image in agreement with these sensations; our pretensions go no further. We are like people looking

at a watch whose case they must not open, who wonder how the watch manages to go. All that we can require of a hypothesis is that it should connect the known facts into a coherent system consistent with the remainder of our knowledge. It is impossible for us to go further.

Consequently the question is not whether the ether really exists or not, but what qualities must be attributed to it in order to explain known facts. Were we to imagine the ether as a gas more tenuous even than hydrogen, we should be on the wrong course and should explain nothing. Assuredly ether must have a very low density. According to the calculations of M. Brillouin one gramme of ether should occupy a volume of, roughly, one cubic kilometre. If we consider that a like volume of air weighs 1,300,000 metric tons, the ether will impress us as being practically imponderable, but it is not a fluid. We may say, however extraordinary it may seem, that it has rather the properties of a solid. Lord Kelvin, the admirable physicist, whose eyes saw farther than the eyes of other men, compared it to a jelly, or to pitch. Like a jelly it quivers at the slightest shock, and vibrations are propa-

gated through it like the circles in water into which a stone is dropped, at the tremendous speed of 186,000 miles per second. But the ether is also viscous like pitch. If on a cake of pitch, perfectly solid in appearance, we place a lead bullet, we find that it sinks little by little, so that after a year's time it has penetrated five or six centimetres into the pitch. Similarly material bodies immersed in the ether can change their place in it, thanks to its viscosity, but at much higher speeds than the ball in the cake of pitch. Thus the earth in its annual movement forces its way through the ether at the rate of thirty kilometres per second.

As a matter of fact all these comparisons are lame; the ether differs profoundly from matter, and only an infirmity of our nature compels us to borrow our comparisons from this matter, which alone is known to our senses. In reality it is only in the language of mathematics that precise expression can be given to the properties of the ether. This expression has been provided by Maxwell, Hertz and their successors. It sums up our knowledge, still very incomplete, of the nature of the ether.

Matter and ether, these are the materials with which our scientific theories have tried to construct an image of the world. This structure was being built up gradually and methodically, when at the end of the nineteenth century an event, which all must remember, gave a great impulse to the evolution of science and imparted to it an unexpected turn. The great discovery of Röntgen, and those of Becquerel and of Curie, revealed to us a new world. Scientists, who were at first dazed by the mysterious X of the new rays, are gradually recovering equanimity, thanks chiefly, it must be said, to the audacity of the physicists of the Cambridge school under the leadership of Professor J. J. Thomson, whose labours have recently met with their deserved reward in the shape of a Nobel prize. All our views regarding matter have to-day been so completely remoulded that before proceeding farther we must devote some space to the explanation of this metamorphosis.

Let us consider a Röntgen ray bulb. It consists of a glass vessel into which penetrate two metal wires connected to two platinum

discs, the anode and the kathode; a practically complete vacuum has been produced in the bulb, leaving barely one millionth of the gas which originally filled it, after which the bulb was closed. If we now send an electric current through it from the anode to the kathode marvellous things are to be observed. Outside the tube the marvel consists in what everybody knows as X rays or Röntgen rays. We shall not describe them, but merely recall the fact that to-day physicists attribute them to movements of the ether, propagated in isolated waves, whereas luminous waves are propagated in regular and equidistant series. The difference between light and the X rays is therefore comparable to the difference between the regular sound of a musical instrument and the rattle of musketry. Other equally extraordinary phenomena, though of an entirely different nature, occur inside the tube. From the kathode, and perpendicularly to its surface, a flow of something escapes, and continues to move in a straight line as long as it finds space before it in the tube. This kathode flow carries with it negative electricity, which can be collected and its quantity measured. At the same time, in

the opposite direction, another current is flowing which carries positive electric charges. Now, since electricity has been known, never have electric charges been seen existing independently of a material support. So the logical inference is that these electric charges emanating from the kathode are borne by grains of matter; the gas in the tube must have separated into two parts, which travel in opposite directions bearing contrary charges. What happens within the gas seems analogous to what occurs in the electrolysis of acidulated water or of soda lye, and this analogy is one of our chief reasons for looking on these phenomena in the way we have just explained. This hypothesis is capable of confirmation, and that is its chief merit. We can determine the speed and the mass of the material elements which travel in this manner inside the Röntgen tube.

In order to realise this let us examine the corresponding problem of ballistics. Let us consider a ball leaving a cannon at a given angle to the horizon; its trajectory is a curve, a parabola, which we can determine, and the knowledge of this trajectory enables us to find the

initial velocity of the bullet. Thus, the explosive force of the powder being known, we can also measure the kinetic energy of the bullet, equal to its mass multiplied by the square of its velocity; when the kinetic energy and the velocity are known the mass of the bullet is determined.

The study of kathode rays presents an analogous problem. The velocity of our tiny kathode projectiles is too high for the action of weight to affect them, but other known forces are capable of deflecting their trajectories. Under the action of a magnet or an electrified body we can see the kathode rays curving distinctly, and on the other hand we can measure the kinetic energy communicated to the corpuscles by the electric discharge which puts them in motion.

The above comparison, though somewhat vague, enables us at least to perceive the possibility of experimenting with these atomic dusts. In fact numerous experiments have been made distinct both in principle and in experimental disposition. Nevertheless the results obtained are remarkably concordant; nothing short of this

could have rallied physicists, at first sceptical, round the theoretical views of the English school. They all agree to-day in admitting that the kathode stream consists of material particles, each with a mass equal to one thousandth of the mass of an atom of hydrogen. We have here a new material element, which has been called an *electron* or *corpuscle*, and this electron is invariably found to have the same mass, whatever gas may have been left in the Röntgen tube; it further appears unaltered in all the phenomena to be described later on: emission from radio-active bodies, from flames, from sparks, from metals exposed to light; its speed alone varies; it seems therefore to constitute the primordial unit of disaggregated matter.

This shows all the fragility of our theories. Scientists had required centuries to find the atoms, last and indivisible elements of matter; they had succeeded in counting and weighing them, in discovering that each cubic millimetre of the air surrounding us contains ten thousand billions of them, moving in all directions with speeds of nearly 500 yards per second. Suddenly the spectacle changes, the atom falls to dust, and the

electron appears on the scene, a thousand times lighter than the lightest atom. In the presence of such a cataclysm the first and natural impulse was to stick the pieces together and attempt to reconstruct the atom. With the electrons this has been done more or less successfully. To-day the atom of matter no longer appears to us as an indestructible mass but as a sort of solar system formed by a central group or nucleus charged with positive electricity around which negative electrons gravitate in closed orbits. Several hundred electrons are contained in one atom of hydrogen, several thousand in an atom of sodium or of mercury, and they are extremely minute compared with the dimensions of an atom. "If we depict," says Sir Oliver Lodge, "the electron by a printer's dot, the atom on the same scale would be represented by an edifice 160 feet long, 130 feet broad and 40 feet high. In fact the electrons only occupy this space as soldiers occupy a country; they patrol it in all directions at enormous speeds. It is their energy and not their mass that constitutes the unity of the atom."

Thus we find that the infinitely small, which we had thought final, has itself grown into a world, and that experience leads us once more to Pascal's vision:—

"What is man in infinity? Who can understand it? But if he desires to discover an equally astonishing marvel let him study the most minute things known to him. Thus a mite, in the smallness of its body, presents incomparably smaller parts, legs with joints, veins in these legs, blood in these veins, humours in this blood, drops in these humours, vapours in these drops. Let him exhaust strength and invention in the further division of these last things, and let the last object which he can attain form the subject of our discourse. He will perhaps think that this is the smallest thing possible in Nature. I will show him a new abyss within it. I will depict not only the visible universe but all that he can conceive of the immensity of Nature within the bounds of this imperceptible atom. He will see in it an infinitude of worlds, each with its firmament, its planets, its earth in the same proportions as the visible world, on this earth animals, and finally mites, in which he will

discover all that the original mites showed, and he will again find in these the same parts *ad infinitum.*"

Such is our present position. However, let us try to see with the eyes of the mind these complex atoms wherein gravitate thousands of electrons. These things are living an intense life, they are vibrating in the midst of the ether. Hence it is easy to conceive that from time to time a corpuscle should forsake its trajectory and shoot into space, like a stone thrown from a sling. This will occur when the surrounding ether is traversed by unusually sudden and rapid waves; this is the effect produced by X rays and certain luminous radiations, or when an increase of temperature raises the speed of the corpuscles and puts strain upon their trajectories until they break, as actually happens with flames and incandescent solids. There are even bodies, known as radio-active bodies, which decompose spontaneously and keep up a ceaseless bombardment of space with their electrons.

In consequence of all these causes the world is full of wandering corpuscles. Hot springs,

numerous minerals, flames, metals exposed to the sun's light, even snow, falling rain and leaves of trees, are emitting them incessantly. The experiments which reveal this emission are extremely simple; so it is a subject of surprise that all these things should have escaped our attention so long. But such is the eternal history of the progress of science, and the world is still full of mysterious things invisible to us but which the eyes of our successors will see as our own distinguish the light of day.

Physicists possess to-day numerous means of producing corpuscles, and are able to define their trajectory and determine their speed. They dispose of an artillery whose projectiles, all of the same mass, make up for their minute size by their enormous speed. Thus the electrons discharged from a metal plate exposed to ultra-violet light have a speed of a thousand kilometres per second; the electrons propagated in Röntgen tubes and forming kathode rays may, according to circumstances, reach speeds of from 20,000 to 100,000 kilometres, while the rays emitted by radium are still more rapid. Their speed ranges between 100,000 and 297,000

kilometres per second, nearly the velocity of light. Let us note this result. It deserves to retain our attention, because it shows us that the highest speed we can impart to matter is apparently equal to the velocity of the ether waves. It would be unscientific to attribute this coincidence to chance. We shall, in fact, see that an explanation is possible, and at the same time we shall complete our knowledge of the nature of electrons. With this end in view let us resume and carry to its conclusion our comparison between electrons and moving projectiles. Let us consider a bullet flying through the air. Has it only to cut through an inert and motionless medium? We all know that this is not the case, but that the bullet is accompanied by a wake which spreads through the air after the passage of the projectile. This wake is a disturbed region, deriving its movement from the energy of the projectile, so that the energy of the gun is not expended on the mass of the bullet alone, but is partly absorbed by the column of air disturbed by the wake. All these things happen as if the projectile had an apparent mass greater than its real mass. The excess of

the apparent mass over the real mass is insignificant at low speeds, but increases with the speed concurrently with the energy communicated to the surrounding air.

Now all that we have to do is to apply this observation to the infinitely small bullets called corpuscles, and to the ether in which they progress. The electric charge, carried by the corpuscle, gives rise to a true electric current, which appears at each point of the trajectory when the charge reaches it and disappears as soon as the charge has passed. Now a current of this description produces in the surrounding ether perturbations called, in the language of physics, induced currents, and these induced currents, which accompany the electron on its flight, absorb part of its energy, a part which increases with the speed. The corpuscle has, therefore, like the bullet, a true mass and an apparent mass, the latter increasing with the speed. The physicist, Sir J. J. Thomson, whose name has already been mentioned, succeeded in calculating the law of this variation, and found that the apparent mass of the electron would become infinitely great, at a speed equal to the

velocity of light, which simply means that this velocity constitutes a limit which no corpuscle ever can reach, because no matter how great the energy brought into action it could never move a mass which had become infinite.

These theoretical inferences of the English scientist have been fully confirmed by the experiments of Simon and Kaufmann. These two physicists succeeded in measuring the apparent mass of corpuscles moving at different speeds, and they found that it increases rapidly as the speeds approach 300,000 kilometres per second.

We are thus already practically sure that the entire mass of the corpuscle cannot consist of matter. But are we sure that any part of it is really due to matter? A German physicist, Herr Max Abraham, asked himself the same question, and to clear up the matter he subjected to mathematical analysis the case of a hypothetical corpuscle consisting solely of an electric charge without any material mass at all. It still has an apparent mass due to its wake alone, and it is possible to calculate for different speeds the corresponding apparent

masses. The results obtained on this hypothesis agree very well with Simon and Kaufmann's[1] experiments.

The logical inference from all this is evident. The corpuscle is quite free from matter. It is merely an electric charge moving in the ether. The extent of our knowledge regarding the positive nucleus composing the remainder of the atom is small, but M. Poincaré, who is both a great mathematician and an eminent physicist, affirms that if there is no matter in the negative charges the positive charges must also be free from it. Thus the atom has been dematerialised, if one may say so, and with it the molecules and the entire universe. Matter disappears, and we and all that surrounds us remain mere disturbed regions of the ether, determined by moving electric charges. A logical, if unforeseen, conclusion, because it is by increasing

[1] If 1 represents the mass of the corpuscle at low speed, the apparent mass measured is as follows:—

For a speed of		220,000	kilometres	per second	1.3[illegible]
"	"	240,000	"	"	1.53
"	"	260,000	"	"	1.78
"	"	288,000	"	"	2.44
"	"	297,000	"	"	3.16

their knowledge of matter that physicists have been led to doubt its reality.

Are these things certain? One must beware of believing it. To-morrow perhaps the wind of a new theory may sweep away all these hypotheses. We are upon scientific ground of too recent date for it to be possible to build solid structures. But it is curious to remark that all these modern theories bring us back to the ideas of Helmholtz, one of the greatest geniuses of the nineteenth century. Helmholtz was a smoker, but great men profit even by their faults. The smoke rings which sometimes left the bowl of his pipe and rose slowly in the air revolving on themselves set him thinking. The idea struck him that atoms might perhaps be similar vortices formed within the ether and consisting of ether. He subjected the problem to analysis, and found that in a medium free from viscosity such vortices should persist indefinitely. This is exactly one of the characteristics of the atoms or of the corpuscle. There is nothing absurd in imagining that the two possible directions of rotation of the vortex on itself correspond to the positive and negative electric charges which

we have found attached to the final elements of matter. This would realise that unity to which the logic of our mind inclines, by reducing to a single element the ether, the trinity of matter, ether and electricity, out of which science had hitherto striven to construct the image of the world. . . . But let us leave these fancies of our imagination. No theory, which is beyond the reach of experiment, deserves to be called a scientific theory.

Now, let us conclude with a few words of general inference. As our knowledge of the world is gradually completed by new and more delicate experiments we find that the original conception of it, derived from our senses, is being profoundly transformed, and that new forms are peopling space. Imagine how the ideas of a man would be transformed if, having known the world by touch alone, he were successively to gain his hearing and his sight. But each great discovery of science bestows upon us a new sense, and the world which it makes known to us is neither more nor less real than the world which our hands can touch and our eyes can see, because like the latter it has been revealed to us

by observation and experiment, but it is infinitely vaster and richer. As for the scientific theories which follow each other with such rapidity, we cannot expect them to reveal what lies hidden behind phenomena or what is the final plan of the universe. However, they are something more than wind and smoke — they respect established facts; and if they cannot explain they at least classify them. This is their great, perhaps their only merit. They are attempts at rational classification, attempts which must be recast whenever a new harvest enriches our knowledge. The harvests accumulate ceaselessly, and the palace of hypothesis in which they are stored is ever in process of reconstruction. It is for this very reason that science is alive.

THE INTERIOR OF THE EARTH

THE radius of the earth is about 3950 miles long. Of this enormous thickness a few yards are sufficient for us to live and die in, and we have never penetrated deeper than a mile and a quarter. What is there lower down? Are we resting on a solid block or floating on a raft? It is hardly credible that, after so many centuries of civilisation, we should have progressed so little on this point, that we should know so much about far-off worlds and so little about the interior of our own. But if the earth begins to tremble, or if volcanoes arise, our thoughts turn to the disquieting mystery of the depths and to cosmogonic hypotheses.

We still retain the conception of Descartes and of Newton which Laplace perpetuated in an admirable synthesis. For us the earth is a fragment of the original solar nebula condensed into a liquid sphere, which, while cooling gradually, has covered itself with a solid crust. But on what experimental basis does this belief rest?

The *Exposition du système du monde* appeared in 1795, and the *Mécanique céleste* was published from 1799 to 1825, barely at the dawn of experimental science. Since then the development of geology and physics has been marvellous. If they supply few new arguments they at least enable us to weigh more accurately the old ones and to reach, if not certitude, a high degree of probability. However, we must not allow ourselves to be confused by the theoretical speculations of which science, and especially English science, is full. We must not be disturbed by deservedly famous names nor by the rigour of mathematical reasoning. That Darwin and Lord Kelvin, by postulating an incompressible central fluid, surrounded by an elastic envelope, or that Hopkinson, by depriving this internal fluid of viscosity, should have reached conclusions incompatible with Laplace's theory, proves nothing beyond the inaccuracy of the initial hypotheses. These speculations have not revealed the truth, nor could they have done so. To know it we must examine Nature directly, classify and analyse known facts, and draw the inductions which appear most probable in the present state of science.

First of all, one thing is certain, the earth has been fluid at some period of its evolution. Of this we have two proofs, each sufficient to carry conviction. The first, known already to Newton, is based on the flattening of the earth, but some explanation is necessary to enable us to appreciate its value. The oceans cover three-quarters of the globe, and their surface of equilibrium is placed upon an ellipsoid of revolution, which differs very little from a sphere, as its equatorial radius is only 13½ miles longer than its polar radius. This proves only that the earth rotates. This rotation gives rise to a centrifugal force, which increases from pole to equator with the radius of rotation. Consequently the mass of equatorial waters, being relieved of part of its weight by this contrary force, rises higher than the mass of polar waters, and the ascertained difference of level is precisely what results by calculation from the velocity of rotation.

But let us suppose all this liquid absent, or pumped on to some other planet, leaving the earth's crust quite dry. It would appear to us ridged and irregular, hollowed into profound

abysses and elevated into enormous mountains. If, however, we reduce all these dimensions to the scale of a globe three feet in diameter, mountains and abysses appear to us as imperceptible wrinkles, as shallow furrows at most $\frac{1}{50}$th of an inch deep or high. They are all mere surface accidents. The general form remains obvious; it is still a sphere, slightly flattened at the extremities of its polar axis. The equatorial diameter exceeds the polar diameter by about $\frac{1}{8}$th of an inch.

Thus, notwithstanding the erosion of the waters and the dislocations produced by subterranean convulsions, the earth has not been altered to such an extent that one cannot recognise its primitive shape, and even if our globe were actually solid to the core it must have been fluid in the past in order to have assumed this form.

Another equally conclusive proof is based on the distribution of densities within the globe. We all know the law of universal gravitation which it was Newton's glory to derive from the laws of planetary motion, formulated by Kepler. It teaches us that between any two

material objects there exists a force of attraction proportional to their masses and acting in inverse ratio to the square of their distances. Had it been possible for any doubts to subsist after Newton regarding this attraction, Cavendish would have dispelled them in 1798 by measuring it directly by means of very sensitive balances. The experiment has since been repeated many times, and we now know precisely that two masses, each equal to one kilogramme, and placed one metre apart, attract one another with a force equal to 6.7 millionths of a milligramme. Now, the attraction of the earth for a kilogramme placed at its surface is precisely equal to the weight of the kilogramme. This enables the mass of the earth to be determined by simple proportion; it is found to be 5875 million billion metrical tons. Dividing this figure by the volume of the earth we obtain its mean density, which the most recent determinations fix at 5.56. The earth is on an average five and a half times heavier than water. But this is only the mean density, and it is very easy to see that in the superficial layers of the globe the weight of the heaviest materials is consider-

ably lower than this mean density. Thus the density of marble is 2.7, of lava 2.4, of granite 2.6; hence to compensate for this the deep layers must be heavier. Calculations by Roche and experiments by Airy make it probable that this internal density is about 7. This is approximately the density of the common metals, zinc, iron, and copper. The available data lead to the conclusion that the still denser metals—silver, mercury, gold, platinum—must be confined to the more central regions of the globe, so that disturbances and displacements capable of bringing them to the surface must have been relatively much rarer. This would explain why the most precious metals are also the heaviest.

In any case one fact is certain: that for a considerable depth, greatly in excess of that of the layer of crust altered by external influences, the density of terrestrial materials increases with the depth. Such a result would be inexplicable unless at some period the fluidity of these materials had enabled them to grade according to density. We are thus certain that the earth has been liquid; it is a globe in process of cooling, and

the wrinkles of its crust indicate the shrinkage of its volume.

But then another question arises. What stage of cooling has the earth actually reached? Is it still liquid in its interior, and, if so, how thick is the solidified layer? Or is it only locally that cavities are to be found full of still liquid matter? Or again, is the entire mass solid?

In order to avoid ambiguity in the examination of this question we intend to confine ourselves to facts, and to inquire into the present means at our disposal for ascertaining what is going on within the earth. Among the chief of these may be mentioned the study of stratifications, of magnetism, of the variation of temperature with depth, and finally the study of the movements of the ground and of eruptions.

Hitherto the principal work of the geologist has consisted in differentiating the various formations, ascertaining the chronological order in which they were laid down, their form and superposition. Perhaps the most admirable feature of this work is the certainty with which it has enabled a knowledge of the deep-lying

regions to be inferred from the study of more superficial formations. One can follow within the earth's crust the geological strata encased one within the other and determine the sequence and thickness of the strata that a well sunk at any point of the globe would traverse. Every day brings forth new applications of stratigraphy to mining or hydrological research. But all this science stops short at the granite. What is the thickness of this bottom bed? What is there beneath it? Paleontology is silent and petrology has very little to teach.

The same may be said of the magnetic investigation of the globe, an infant science which gives promise of great things for the future.

It has hitherto confined itself to the determination of magnetic constants for all points of the earth's surface, and has already been able to reveal faults and internal dislocations, which might have for years escaped the perspicacity of geologists. Some day it will no doubt be possible to separate the share of magnetic action due to electric earth currents from the magnetism of the rocks themselves. It will then be possible to begin usefully the study of sub-

terranean magnetism, and to determine the surfaces of which the curves on our magnetic charts are merely the surface traces. This will be of great assistance to stratigraphy. But no one can tell at present whether this means of investigation will enable us to study the metallic masses, whose existence we suspect beneath the siliceous crust which forms the globe's surface.

If the magnetic needle does not, as yet, supply useful indications regarding the deeper regions of the globe, the thermometer instead affords us information of the highest interest. The surface temperature of the ground varies according to place, season, day and hour, and depends closely on the heat received from the sun, and on that radiated by the earth into the atmosphere, but the temperature varies only in a shallow, superficial layer of ground. Even the most extreme temperatures in the year do not affect it to a greater depth than seventy feet. Below this film, sensible to external influences, the temperature remains rigorously constant at every point of the globe. Thus a thermometer kept for over a century in the cellars of the Paris

Observatory has never ceased to show exactly the same temperature, 11.82° centigrade.

But this temperature, while constant in every single position, increases with the depth. This increase has been observed under the most varied conditions in borings, mine shafts, etc. It is also manifested by the high temperature of waters springing from the depths of the ground. The waters of Hammam-Maskoutine in Algeria leave the ground at a temperature of 95° centigrade, and the temperature of the Great Geyser of Iceland, measured inside the funnel and near the surface, mounts as high as 126° centigrade. As a consequence of the same phenomenon water has been found in Siberia unfrozen at a depth of 420 feet, under a layer of ice whose temperature at the surface was 10° below zero. The law of the increase of temperature with the depth is therefore general, and the very rare exceptions observed are easily accounted for by local conditions.

This thermic variation necessarily causes a flow of heat from the hot, internal regions to the cooler surface regions. Therefore the earth is constantly cooling and radiates to the exterior

a quantity of heat which may be estimated roughly at one calorie[1] per square metre per minute. The sun, on a fine summer day, sheds on the same surface in the same space of time a calorific energy twenty thousand times greater. Thus the contribution of the central heat is insensible to us, chiefly owing to its extreme feebleness and partly because it is constant; we are affected only by variations of temperature. These figures enable us, notwithstanding their indifferent accuracy, to estimate in passing the value of an idea which finds frequent expression, viz., Why not take the necessary heat for supplying our industrial requirements from the furnace beneath our feet?[2]

[1] Caloric is the quantity of heat required to raise the temperature of one gramme of water one degree C.

[2] We may recall the words pronounced by M. Berthelot (*Science et Morale*, p. 508) in a most humorous description of the state of the world in the year 2000: "To tap the central heat, all that is needed are shafts sunk to a depth of four or five thousand metres, a task probably within the power of living engineers, and still more of those of the future. There would be found heat, the origin of all life and all industries. At the bottom of these shafts water would reach a high temperature, and would develop sufficient pressure to drive all possible engines. Power would therefore be available at all points of the globe, and thousands of centuries would

No doubt it would be possible to sink borings to depths where the temperature would exceed that of boiling water, but that is not the question. Whatever the temperature the amount of heat available for use could never exceed the supply derived from the central regions. Thus it follows, from the figure given above for that amount, that to develop ten horse power with a steam engine of average efficiency supplied with steam by the terrestrial furnace all the heat passing through something like half a square mile of the earth's crust would have to be intercepted.

While we know beyond doubt that the earth is cooling, it would be equally interesting to determine the law of the rise of temperature in its interior. Here we must leave all hope of certainty and be satisfied with probabilities. Our facts take us no deeper than one mile and a quarter; beyond that we can only proceed by induction. But the probability of this induction depends on the reliability of the observa-

pass before the supply showed any signs of decrease." The great chemist did not look on this as a mere fancy, because this same idea of obtaining energy, cost free, from the earth's central heat reappears in a more recent publication (*Science et Libre Pensée*, p. 192).

tions made in the shallow layer of the earth, accessible to our investigation. The ideal condition would be presented by a layer of ground sufficiently homogeneous to be of constant calorific conductivity throughout, and thick enough to permit the precise measurement of what is called the *geothermic degree*, that is to say, the thickness of ground which corresponds to an increase of temperature equal to 1° centigrade.

This condition was very nearly realised in a boring sunk at Sperenberg, south of Berlin. Out of a total depth of 1380 yards the drill remained for nearly 1100 yards in a bed of rock salt; at the bottom the temperature reached 48° centigrade, corresponding to a mean geothermic degree of thirty-six yards. However, in spite of the remarkable homogeneousness of the formation the thermometer readings taken at different depths were far from showing a regular rise of temperature. In particular the deepest section, between 1170 and 1340 yards down, gave a geothermic degree of 145 yards.

These results were at first interpreted unfavourably to the central heat theory. Carl

Vogt took occasion from them to dub the hypothesis "an avatar of the ancient Tartarus myth," while Mohr wrote that the results obtained in the Sperenberg boring had cruelly annihilated the ancient doctrine of the central heat.

It was premature to draw from this experiment such final conclusions, especially knowing how greatly the calorific conductivity varies even in apparently homogeneous formations. Even at Sperenberg one measurement taken between 330 yards and 440 yards deep gave a degree of 154 yards, while the measurements immediately above and below gave twenty-three and thirty yards respectively. The wiser course was to continue making experiments. This has been done. At Schladebach, in Saxony, a boring 1920 yards deep was sunk. The temperature at the bottom reached 56° centigrade, and the mean geothermic degree was forty yards. Finally at Paruchowitz, in Silesia, a boring was sunk 2200 yards into the ground. At the surface the temperature was 12°; at the bottom it reached 69.3° centigrade, giving a geothermic degree of thirty-seven yards.

These determinations seem to indicate that the thermic progression is very regular, and do not show any tendency for it to decrease at the extreme depths. It therefore seems incontestable that the temperature must continue increasing to much greater depths. The temperature at a depth of about four miles will certainly be, as stated by M. de Lapparent, very near 170° centigrade. But does it ever rise high enough to melt the deep-seated rocks? We must examine this question in detail.

A rise of 1° every 38½ yards would lead to a temperature of 2000° centigrade at a depth of about forty-four miles, and such a temperature is sufficient to melt in the retorts of our laboratories all the metals and nearly all refractory materials. The melting temperatures of the principal rocks are known to-day with accuracy, thanks especially to the researches carried out by the U.S.A. *Geological Survey.* Basalt, the commonest constituent of the lavas erupted by volcanoes, melts at 880°, and the components of granite, mica, felspar and quartz have their melting points at 1440°, 1520° and 1775° C.

But these melting points certainly do not remain unaltered at the enormous pressures to which the internal rocks are subjected by the weight of superjacent material; at a depth of forty-four miles the pressure must reach nearly 20,000 atmospheres. As such pressures have never been obtained in a laboratory we do not know how they might affect the properties of matter. It is, however, highly probable that they would not raise the melting temperature more than 400° or 500° centigrade.

According to the determinations of the *Geological Survey*, diabase, which under normal conditions melts at 1170° centigrade, would reach its melting point under a pressure of 10,000 atmospheres only at 1420°, on the assumption that the melting point continues to alter at these high pressures at the same rate as at lower pressures; but other experiments show that the rate of progression declines with the increase of the pressure.

Taking into consideration all these experimental results we may conclude, with some degree of probability but not of certainty, that the rocks forming the lowest solid bed of the

globe reach their melting temperature at a depth of between forty and sixty-five miles, which would also be the mean thickness of the solid crust of the globe. This hypothesis is supported by observations of another order.

Those who believe the form of the earth to be invariable are strangely mistaken. Their mistake is not shared by the inhabitants of some central American provinces, who have never seen a year go by without the earth shaking under their feet.

In our own countries the vibrations, though weaker, are not less frequent. M. Fuchs counted 1184 earthquakes between 1865 and 1873, and a Scientific Committee registered 166 in Switzerland during the single year 1881. In addition to the violent shocks which force themselves on our attention by their disastrous consequences slighter tremors are continually running through the ground. They are recorded in numerous observatories by instruments called seismographs. The simplest consists of a pendulum, free to oscillate in every direction, and provided at its lower extremity with a marker.

As soon as the ground shakes the pendulum swings and traces on a sheet of paper fixed underneath a line of varying amplitude in the direction of the motion.

These undulations come from afar. At times they seem to emanate from a single centre, at others to start from all points of a certain line; again the shocks originate in a more or less extensive area, from which they are propagated, gradually losing strength as they proceed. We shall only consider the simpler case in which the waves derive from a single centre.

Suppose such a disturbance to take place in a country where the internal structure of the ground is as uniform as possible. At the first shock all clocks stop, and record in this way at every point of a vast territory the precise instant when the ground began to shake. One of all these clocks will be found to have stopped first. The spot which it occupied is called the epicentre of the earthquake, that is to say, the original shock occurred underneath this point at a distance which remains to be determined. Now the records of the various clocks disclose the points reached by the seismic wave one, two,

three and four seconds after its origin. If the centre of disturbance were on the surface, and if the ground were homogeneous, these positions of the surface wave would describe round the epicentre concentric and equidistant circles. If, on the contrary, the origin of the disturbance were at the very centre of the earth, the wave would reach simultaneously every point of the surface. In reality all cases occur between these two extremes and much nearer the first than the second. The distance between the circles of disturbance decreases as they are removed from the epicentre; from their positions it is possible to estimate with some accuracy the original depth of the disturbance. The method just mentioned is, however, not the only one, and the ingenuity of geologists has multiplied methods and observations concerning this very important question.

Now, all observers are agreed regarding one point, viz., that the centre of disturbance is invariably situated within a short distance from the surface. This is the result of one hundred and fifty observations, made with the greatest

care, among which we may quote the following.[1]

Date.	Locality of the Earthquake.	Depth of the Centre of Disturbance in Miles.
1884	Ischia	.62
1857	Calabria	3.41 to 4.7
1872	Central Germany	11.18
1884	Andalusia	11.18
1887	Genoese Riviera	11.18
1886	Charleston	18
1869	Cachar	29.8

Thus all earthquakes investigated have arisen within the thickness assigned by us to the solid part of the globe. Is this merely an accident? Apparently not. Whether we attribute earthquakes to the collapse of cavities excavated by the erosion of subterranean waters, or whether we consider them ruptures and dislocations produced by the pressure of internal lavas, striving to force a passage through the fissures of the crust, we must postulate a solid medium. The recent earthquakes in California, which partially destroyed San Francisco, have once more enabled us to ascertain that these cataclysms are always accompanied by a dislocation of the

[1] De Lapparent, *Traité de Géologie.*

solid crust; therefore the fact that the origin of similar disturbances has in no case been traced to the deeper regions of the globe supplies a new and powerful argument in favour of internal fluidity.

But we have better proofs than these arguments, because we are able to appeal directly to experiment, and to utilise the earthquake to auscultate the globe in its depths. Some of the oscillations recorded by seismographs are propagated at velocities between three and four miles per second, and are probably transmitted through the solid crust of the globe. Experiments with explosives, carried out in Japan, have shown the velocity of propagation of waves through the earth's surface to be about two miles per second; through granite the velocity exceeds three miles. But besides these the instruments record other and much more rapid waves (about eight miles per second). These tremors, which can cross the earth from end to end in less than half an hour, must pass through mediums entirely different from those forming the crust. We must add, however, that physics is not at present in a position to inform

us regarding the nature of these internal media.

Thus the study of sudden convulsions of the ground confirms the admitted hypothesis concerning the probable thickness of the solid crust. But the ground is also subject to other motions, which would certainly have escaped our notice, if long and careful observation had not established their existence beyond a doubt; these are secular variations, elevations, subsidences and lateral displacements, which are continually modifying the general configuration of our globe.

The sea supplies in its unchanging level a surface of reference which enables us to calculate these displacements. The total volume of water in the ocean has, in fact, not varied sensibly since the commencement of historic time, as otherwise the coast line would be found to have risen or sunk as a whole. Now this is not borne out by our observations, and we cannot admit the view of the ancients that the earth was once a small island, and has gradually grown by the deposit thrown up by the waves. The movements of the ground have invariably been of

an oscillatory character, causing some regions to emerge while others were gradually sinking.

No example of these long-period variations is more widely known than that of the Pozzuoli district. Three columns belonging to the ruined temple of Serapis are standing there to-day with their base immersed in the sea. These columns have been pitted with holes by marine molluscs at a height of ten feet above present sea level, and thus bear witness to the successive changes in the level of the sea in this region. As a matter of fact the ground about Pozzuoli continued to sink steadily from Roman times to the fifteenth century. In 1538 an eruption of Monte Nuovo caused a sudden upheaval, and since then the ground has again been sinking gradually.

Here a purely accidental fact compels our attention to the progressive movements of the ground, but the area affected around Pozzuoli by these movements is too restricted for them to be considered otherwise than purely local manifestations of volcanic action.

The study of the northern regions where the earth first consolidated affords more typical phenomena, owing to their freedom from

volcanic action and earthquakes. The Scandinavian peninsula and Canada have for centuries been undergoing slow variations in level which were manifest as early as the end of the glacial period. We do not mention the movements of this primitive epoch, because a perfectly reasonable theory attributes them simply to the expansion of the ground due to the rise of temperature which followed the glacial period. We must rely on more recent documents.

As early as 1702 it occurred to the physicist Hjärne to have reference marks cut on the rocks lining the Swedish coast. Linnæus and Celsius made other marks in 1728 on a cliff of the island of Loeffgrund, and already in 1748 they observed an apparent fall of the sea level, that is to say, an actual rise of the land, seven inches in height. In 1849 the vertical emergence had grown to three feet six inches. While the ground is rising in the neighbourhood of the Gulf of Bothnia, the southern extremity of Sweden is instead sinking slowly into the sea; the mean level of the ground has sunk five feet since Linnæus made his observations, and several

streets of the town of Malmö have disappeared into the Baltic Sea.

Similar observations have been made in every part of the world. In France Picardy is gaining on the sea, while Normandy and some parts of Brittany are sinking into it. Aunis and Saintonge are rising, while Gascony is sinking.

Some of these displacements may be explained by local or superficial causes, or by modifications of the regular course of the tides. But for many others a return to the hypothesis of the internal fluidity of the globe is imperative. An entirely solid mass, cooling and contracting by jerks, gives way suddenly when its limit of elasticity has been exceeded; only a fluid mass can present the slow, continuous movements proved to be universal by our observations.

We might fancy that almost unawares we have watched the work which, continuing for thousands of years, has built up our great mountain chains and hollowed out the abysses of the sea. As the earth cools the fluid mass within contracts more rapidly than the crust, because fluids are always more expansible than solids, and for this reason the crust wrinkles like

the skin of a fruit when it withers; grooves and furrows appear on it, some due to a slow bending of the crust, others, when a local cause acts more violently, to fractures, which produce faults and dislocations in the solid mass. In this manner internal and external forces act together, and it is their joint action that slowly ages and wrinkles what Suess calls so appropriately "the face of the earth."

None of the numerous arguments advanced in favour of the internal fluidity of the globe appeal so forcibly to current opinion as the existence of volcanoes. Nothing could be more natural than to treat these volcanoes as natural vents of the central liquid. It would be injudicious to accept this explanation without close examination and without a knowledge of the objections it has provoked.

The admission of the internal solidity of the earth requires, in order to account for the expulsion of molten material and the enormous liberation of heat which occur during eruptions, the intervention of some source of energy. The work due to the contraction of the globe has been thought sufficient; it is supposed to produce

fractures within the solid mass, which allow some rocks to be crushed by the weight of the superjacent formations. This mechanical work becomes the source of heat. In 1872 Sir Robert Mallet endeavoured to compute its magnitude. His experiments led him to the conclusion that the pulverisation of one cubic metre of rock would produce sufficient heat to melt 300 kilogrammes of ice. He inferred from this that the annual crushing of one quarter of a cubic kilometre of rock would be sufficient to furnish the entire energy of volcanic action at the present day. We quote this explanation chiefly to expose the flagrant impossibilities which militate against the assumption of the earth's complete solidity. How explain on this hypothesis the way in which a purely local action, by transferring materials from within the earth to the surface, could result in the production of enormous mountains, or even of entire islands, such as Hawaii or Iceland? Should we not rather expect to find eruptive centres surrounded by gigantic subsidences? For example, the lava erupted by Jökull in Iceland would have produced a cavity of sufficient capacity to sink

the ground to a depth of more than a hundred yards over a surface of over a hundred square kilometres, while distributed over the surface of the globe it would not have reduced its radius by $\frac{1}{1000}$th of an inch. Mallet's theory is equally incapable of explaining the enormous outpourings of gas which accompany eruptions and transform the vents of volcanoes into regular cannon trained against the sky and discharging their projectiles to a height of several miles. On the contrary it is reasonable to admit that under the pressure of the primitive atmosphere, which must have been three hundred times greater than at present, the molten mass of the globe dissolved these gases which to-day escape through the fissures of the crust.

A more ingenious and more frequently-advanced hypothesis seeks in chemical reactions the origin of volcanic manifestations. Already at the end of the seventeenth century Nicolas Lémery hit on the idea of burying a mixture of iron filings and flowers of sulphur. When wetted with warm water the sulphur and iron combined with production of heat, the ground swelled and steam could be seen escaping from a

sort of crater. This was Lémery's volcano. A hundred years later Volta explained in similar manner the exhalations of the Tuscan Maremma by the decomposition of surface animal and vegetable matter, buried for centuries under the detritus of the Apennines. Werner at the same period sought at Freiberg identical views.

To-day nothing remains of these rudimentary explanations, and it would be loss of time to demonstrate their inadequacy. Another hypothesis, it is true, may be linked with the chemical hypothesis; it attempts to explain volcanic paroxysms by the gradual infiltration of sea-water and the effect of its contact with the incandescent inner matter. Fortunately it is unnecessary for us to express an opinion on this much-disputed question; whatever solution is adopted it cannot affect the probability of the internal fluidity of the globe.

But though the study of volcanic action leads one to admit the existence of molten masses in the interior of the globe, one might yet suppose these liquid masses not to be continuous but concentrated in great cavities, each feeding a single volcano or all the volcanoes of

one region. This might explain the independence of the paroxysms and the difference of the products of neighbouring volcanoes. The Italian volcanoes, though very close together, act usually as if thousands of miles apart. There is, as a rule, no correspondence between their eruptive periods, and the lavas emitted are far from identical in chemical composition, as might be expected if they communicated with adjoining points of the same internal mass. Similarly no relation has been discovered between the periods of activity of the two volcanoes on Hawaii, whose craters are only twenty miles apart.

Let us, however, examine the facts more closely. First of all, if the independence of volcanoes is the rule it is not a rule without exceptions. In 1865 Etna, Vesuvius and Stromboli were in simultaneous activity, and eruptions occurred a few months later, in January 1866, at Santorin in the Cyclades. Similar coincidences have been observed frequently enough with regard to the Central American volcanoes. At the present it is difficult not to attribute to a single cause the recent earthquakes in Calabria,

the disappearance of the island of Ustica near Sicily, and the eruption of Vesuvius.

Now one single observation of this kind is sufficient to establish the common origin of several volcanoes; on the other hand, it stands to reason that the volcanoes of the same region should in general be independent. If any cause happens to disturb the equilibrium of the internal mass the increased pressure will fracture the crust at the point of least resistance, and the entire volcanic activity will concentrate in this crack. This is why, in times of paroxysm, the same regions, like ill-healed wounds, form a vent for the internal flux. However, when the convulsions of the crust produce a new line of fracture, or the hardened lavas choke up the old vent, the next eruption will take another direction.

Therefore one must not be surprised to see very rarely neighbouring volcanoes in simultaneous activity. Neither must one draw conclusions from the difference of the products erupted, because one identical volcano is found to supply products of the most varied nature. At Teneriffe the upper lavas contain over 58 per cent. of silica, the intermediate ones contain

only 52 per cent., and for those at sea level the percentage drops to 47. The content of iron varies in inverse ratio. In fact the lavas issuing from the crater of a volcano must not be considered to have arrived there unaltered from the centre of the earth. They have necessarily melted and carried off part of the lining of the passages through which they have been flowing for many miles. Moreover, it would be childish to imagine the internal fluid mass rounded into a perfect sphere; the corrugations of the crust must have made themselves felt inside, more perhaps than outside, where various causes tend to plane and level the surface, so that some volcanoes may be fed from relatively superficial regions, while others have their source at greater depths, and draw their lavas from remoter and consequently differently-constituted strata.

It seems, therefore, impossible that each volcano should be provided with a corresponding independent liquid cavity. It becomes almost necessary to admit the existence of vast liquid lakes beneath each of the chief volcanic regions. Moreover, 320 volcanoes are known to have been active during the last three centuries, and are

distributed over all the continents, and the ocean covers, perhaps, a greater number, as almost all dredgings made in the Pacific have brought up traces of volcanic tufas. And if to these centres of activity are added all extinct volcanoes, which are studded over the face of the earth like boils scarcely healed, one recoils from the number of separate cavities and lakes required to account for their existence. As M. de Lapparent points out the entire Pacific and all the surrounding land would have to be considered to rest on a lake of lava. Under these conditions it is difficult to imagine the existence of solid walls between such liquid masses; it is difficult to understand how any differences of chemical constitution or of temperature could have raised walls of this nature within a mass originally entirely liquid.

On the other hand the general trend of these phenomena can be interpreted by the assumption that the folds of the crust have formed within the globe deep intercommunicating cavities, which subdivide the earth into sufficiently independent regions for a disturbance occurring in any one of them to leave the re-

mainder practically unaffected. This assumption appears all the more probable if we remember that these disturbances which terrify our pettiness are, in relation to the dimensions of the earth, mere imperceptible tremors.

Thus all the positive data of science lead us to the same conclusion. The certainty that in the past our globe has been liquid is followed by the probability that it is still liquid in parts, while some more hypothetical data give us an idea of the possible thickness of the actual solid crust.

This confirms in one of its essential parts the great synthesis of Laplace, which during the last hundred years has formed the basis of all our scientific cosmogonies. This synthesis has thus had the double merit of gathering the known facts into one body of doctrine, and of satisfying our reason, because by prolonging geology into the past, as geology prolongs history, it has thrust the problem of origins into the infinite and has freed our mind from the obligation of conceiving a time before which nothing existed. It has freed our mind with regard to time as

Galileo, two centuries earlier, freed it with regard to space by showing us stars upon stars behind the stars then known, and shattering the diamond sphere in which the ancients had attempted to enclose the world.

THE SUN

FOR most human beings the sun is still a "globe of fire," and even the most learned scientist has little to add concerning it. However, compared with the ignorance of past ages our own ignorance appears less. Anaxagoras attributed to the sun the size of the Peloponnesus; Anaximander considered it to be a circle twenty-eight times greater than the earth and having a central opening through which its rays pass. Xenophanes believed the sun to be formed by fiery clouds, whereas Parmenides thought that it fed on the dry vapours of the Milky Way; Cleanthes supposed it to be nourished by the exhalations rising from the earth. Moreover, they all considered the light and heat of the sun and stars to be incorruptible, that is to say of a far superior essence to the heat and light which we produce on the earth. We can afford to smile to-day at these chimeras, but it is of more use to learn how science has enabled us to get rid of

them by establishing a certain number of precise facts. This will be the more easy since we have reached our knowledge of the sun by a few paths only: by descriptive astronomy, measurement of solar radiation, direct telescopic observation, spectroscopy, and finally by observation of the sun's eclipses.

The chief purpose of descriptive astronomy is to determine the chart of the heavens and the movements of the stars. It shows us that the sun is a sphere of 1,300,000 times greater volume than the earth. Around the sun revolve our globe and the other planets, according to the laws discovered by Kepler and summed up by Newton in the wonderful synthesis of universal gravitation. These conclusions, which recapitulate an enormous number of observations and measurements, have enabled us to determine other facts of the greatest importance for our investigations. Thus the elliptical trajectory of the planets may be considered as due to a fall of these bodies caused by solar attraction, in the same manner that the orbit of a projectile fired from a cannon is the result of terrestrial attrac-

tion; our knowledge of Kepler's laws enables us to calculate the velocity and the acceleration of this fall and to deduce from them the force which causes it. This force, solar attraction, depends on the magnitudes of the two masses attracting each other, and if one of these is known it enables us to calculate the other. Now we know the actual mass of the earth, thanks to an experiment of the English physicist, Cavendish, repeated and improved by many subsequent experimenters, and we are thus able to calculate the mass of the sun.

We are able then to weigh the stars, or, to be more accurate, to compare their masses with the mass of our kilogram. I do not reproduce the formidable numbers which result from the necessary series of calculations, because what interests us is less the magnitude of the masses than their ratio to the volumes of the stars, that is to say, the densities of these bodies. We find thus that, whereas the density of the earth is approximately 5.5, that is to say five times greater than the density of water, the density of the sun is about 1.45, or four times less; these are, of course, averages. On the earth, for

example, the external crust consists of the lighter bodies, whereas at the centre the density is perhaps as high as 7, which is practically the density of iron. Probably similar conditions prevail in the sun.

The smallness of the sun's density is deserving of attention, because it allows us to infer that the bulk of the sun cannot be in a liquid, or still less in a solid state. On the contrary, the calculations of Schuster show that a gas raised to the high temperature probably existing in the sun would, in consequence of the conditions of internal pressure, present more or less the density inferred by us from experience. This hypothesis[1] is distinctly conjectural and must be treated accordingly; it is of the nature of a probability, and scientists have discovered by experience that probability is a bad criterion. However, we may adopt for future use the fundamental idea that the solar mass is probably composed of gases and vapours at a high temperature and subjected to enormous compression.

[1] As recently as 1887 Lord Kelvin considered the sun to be liquid.

Our knowledge of the sun's mean density is practically the only experimental fact known to us regarding its internal nature; this is not surprising since we know absolutely nothing concerning the interior of the earth which we inhabit. All that remains to be told about the sun concerns its surface, the only part which sends radiations to us; these radiations constitute actually the sole intermediary between us and planetary space. Fortunately we have many methods for examining them.

A first method consists in determining what is called the *solar constant*, that is to say, the total quantity of energy radiated by the sun to the surface of the earth. This is obtained with ease by exposing to the sun's action *actinometers*, that is to say, thermometers with their bulbs coated with lamp black, which absorb all the rays falling on their surface. The increase of temperature recorded by these instruments enables us to measure the quantity of heat radiated by the sun. By proceeding in this manner Pouillet, Crova and Violle ascertained that the quantity of solar energy radiated annually to our globe would be capable

of melting a layer of ice, covering its surface to a depth of forty metres. Starting from this figure nothing could be simpler than to calculate the total quantity of heat radiated into space by the sun; the colossal number obtained by these calculations is itself of no great interest, but it suggests a question which has hitherto remained unanswered. By what means has the sun, during the ages, made provision for this expenditure of energy? Its brightness, practically constant during many centuries, prevents it being looked on simply as a hot body in process of gradual cooling. Under these conditions 3000 years would be sufficient to extinguish it. This constancy of temperature has been attributed to various causes, such as a ceaseless rain of meteorites upon the surface of the sun, or to chemical reactions between the elements which constitute the sun, or to a progressive compression of its nucleus. The last of these hypotheses is the only one which is free from insuperable difficulties, but, while nothing is known to contradict it formally, it remains in the air and unsupported by experimental confirmation. The discovery of the radio-active bodies has

also suggested a hypothesis, which is no less conjectural than the others; the presence of two grammes of radium per ton of solar substance would be sufficient to account for quantitatively the energy emitted by our central orb as well as the remarkable constancy of its emission.

But more important for us than the amount of the sun's total radiation is the determination of its temperature. This is an essential datum for ascertaining what materials compose it. Physicists, as a rule, determine the temperature of a body by the amount and nature of its radiation. The sun, however, presents conditions which would render this solution very unreliable. It would be dangerous to apply the laws governing our small, dim fires to this powerful and radiant furnace. The absorption of the sun's rays by the two atmospheres surrounding the sun and the earth must also be taken into account, and this presents considerable difficulty. These two causes account for the surprising differences shown by the various evaluations of the solar temperature. Waterston estimated it at 10,000,000° centigrade;

Father Secchi, in 1875, found it reasonable to be satisfied with half that figure, whereas Pouillet, and in 1875 Violle, decided for a temperature of 1500° C. Later observers have, however, come to an agreement; the researches of the American physicist, Langley, have led to more reliable determinations. By relying on the quality and distribution rather than the quantity of the different radiations which bodies emit according to their temperature, a value of 7000° has been found for the sun's approximate temperature.

When we remember that the temperature of a casting of molten steel is roughly 1800° centigrade, and that the electric arc, in its hottest part, reaches 4000°, we can understand that while the probable temperature of the sun is higher than any obtainable in a laboratory it is, however, not too remote for us to form an idea of the properties of matter at such a temperature. If the sun's temperature were of the order suggested by Waterston and Secchi all hope of positive knowledge concerning its nature would have vanished. Even now we must remember that nothing is known regarding the temperature of the sun's interior. Langley's

computation applies solely to the luminous layer, which alone sends radiations to us. We can only conjecture that the sun's temperature decreases in general from the centre to the periphery.

Our knowledge of the sun owes its chief progress to the direct telescopic study of the luminary's surface. As long as we are satisfied to look at it with the naked eye or through a coloured glass its disc appears uniformly bright, scarcely less at the edges than at the centre, and on rare occasions a spot of unusual size can be distinguished.

It was only with the help of the telescope that our investigations could be carried further, and this immense improvement in our means of investigation dates from Galileo, who by the conjunction of two lenses invented, or reinvented after the Dutch opticians, the terrestrial and astronomical telescopes. With these instruments, which were then very imperfect, and of low magnifying power, Galileo gave fresh impulse to the science of solar physics, which finally cost him his eyesight.

The invention of the reflecting telescope marked a further advance; in this invention, successively improved by Gregory, Newton, and especially by Sir William Herschel, one of the lenses is replaced by a concave mirror. No one has known more thoroughly, or described more minutely, the heavenly paths than the celebrated astronomer of Slough. No one has had at his disposal more powerful instruments. Herschel found in England the necessary support to enable him to construct instruments whose magnifying power has never been surpassed. Such was the famous telescope, forty feet long and six feet in diameter, completed in 1789. However, this instrument showed Herschel that the most powerful telescopes are not always the best for purposes of observation; their enormous size makes them difficult to handle and distorts the image on the mirror; the draught in the tube, the ceaseless and unavoidable agitation of the air, the expansions caused by the heat of the sun all disturb the normal course of the rays. For this reason modern observers prefer to use instruments more modest in appearance but capable of equally good results.

The Sun

Among those to whom we owe our knowledge of the sun's disc a leading place is due to Father Secchi, director of the observatory of the Collegio Romano, whose observations, untiringly concentrated on this single object, have been condensed into an admirable book.[1]

We may add that during the last thirty years photography has been of great use to observers; by enabling them to fix the most transient details of phenomena it has provided a means for studying them at leisure and drawing from them fruitful comparisons.

Let us consider now the facts which the study of the sun's surface has revealed. We find first of all that this surface, far from being uniform, appears on the contrary irregular and undulating, and, under strong magnification, seems covered with a multitude of little bright grains, like grains of rice, separated by a dark network; in some places more extensive bright masses appear, called faculæ; the grains may be two to three kilometres long, the faculæ perhaps ten times longer. It is, however, the sun-spots which form the most striking feature of the solar

[1] *Le Soleil.* Gauthier-Villars, Paris, 1875.

disc and supply the characteristic element in the monotonous brightness of its surface. If they did not exist, or if we were unable to study them, our ideas of the nature of the sun would be very uncertain.

Nothing could be more irregular than these spots; they are of all dimensions, positions and forms. Some, called pores, look like mere black spots under the highest magnification; others, visible to the naked eye, are several times larger than the surface of the earth. Their formation and changes are sometimes slow, and sometimes disconcertingly rapid.

"On July the 28th, 1865," relates Secchi, "nothing extraordinary was to be seen, neither pores nor faculæ; on the 29th only three black points; at 10.30 o'clock on the 30th we were surprised to find the centre of the disc occupied by an enormous spot, the mean diameter of the disturbed region being about 4½ times the diameter of the earth. At the centre we noticed a heap of luminous matter, apparently in whirling motion and surrounded by many rents. Within this chaos four centres of motion could be distinguished. On the left was visible a vast

opening, surrounded by tongues of fire, flickering in different directions, and in the midst of these tongues could be clearly distinguished some semi-luminous veils surrounding a blacker cavity. Above there was a second centre smaller than the first; on the right a wide and more or less S-shaped slit, and finally on the lower part there was to be seen another elongated and curved slit, offering to the eye a disorder which beggars all description. Between these four cavities was a heap of faculæ and luminous matter, having the appearance of a boiling mass.

"The whole was animated by tumultuous and extremely rapid movements. The next day the aspect had entirely changed and the length was almost double. On the following days the mass, intervening between the four openings, gradually became a penumbra upon which were scattered luminous grains. Then the centres became isolated and more pronounced. On August the 27th the large S-shaped opening was still there; on September the 17th only pores and faculæ remained visible; finally, in October, not a trace was left of this immense

perturbation which had agitated the sun's atmosphere."

All sun spots have a similar history. Nevertheless, in all this infinite variety of changing forms certain elements remain constant. In the first place all spots are observed to contain an almost entirely dark central part called the nucleus, surrounded by a grey zone, the penumbra, which, under high magnification, can be dissolved into a series of elongated elements alternately bright and dark, giving the impression of a furrowed slope surrounding a dark, yawning hole.

Another fact of the greatest importance is that the spots revolve round the sun. Certain spots, and especially those which are regular and more or less round, develop very slowly, and can be observed for several months, but they do not remain always in the same place; they may be seen crossing the solar disc from its eastern to its western border. This semi-revolution has an average duration of fourteen days, after which the perturbation passes on to the invisible side of the sun and re-appears on the eastern edge after a further period of four-

teen days, to start on a second, sometimes even a third and a fourth revolution before it vanishes entirely. The earliest observers had attributed these phenomena to the transit of planets in front of the sun, but from the time of Galileo this hypothesis has been abandoned because several co-existing spots are frequently seen at the same time to cross the sun on parallel lines, and in addition the faculæ appear to follow the same rotary motion. Only one explanation can account for all the details of this movement, viz.: the luminous surface of the sun rotates as a whole round an axis which is the line between the poles of the sun. The period of the rotation [1] is about $25\frac{1}{2}$ days.

This rotation of the solar surface has been confirmed by experiments based on an entirely different principle, which may be rendered comprehensible by the following parallel. When two trains are moving in opposite directions and pass one another, a traveller in one of the trains would notice that the whistle is of a higher pitch

[1] Not twenty-eight days as might be inferred from the duration of their apparent movement from edge to edge of the sun, because the translation of the earth during that period must be taken into account.

when the two trains are approaching, and of a lower when they are receding. The reason for this fact has been given by Doppler in 1842. When the observer moves towards the waves of vibration radiating from the whistle he receives a greater number per second than if he were stationary; on the other hand he receives fewer when he moves away from the source of the waves. This proposition is equally applicable to luminous vibrations. When a luminous body emitting a simple radiation is approaching or receding from the observer at a high speed the light appears to correspond in the first case to more rapid vibrations, and in the second to slower vibrations. Now, as each radiation is defined by its position in the spectrum, extending from red for slow vibrations to violet for rapid vibrations, the position occupied by the radiation will move towards the violet, when its source is approaching, and towards the red when it is receding. Therefore, if with the spectroscope we first sight the sun's eastern and then its western edge, and note the position in the spectrum of a given radiation emitted by each of the edges, we shall find a slight but per-

ceptible difference in the two positions, and by measuring the distance separating them we shall be able to determine the speed with which the sun's eastern edge is approaching us and the other edge is receding, owing to the rotation of the orb on itself. The results obtained by this method agree with those deduced from the displacement of the sun spots.

The fact that the sun rotates, though of great intrinsic interest, would not have claimed so much of our attention if it did not lead to another fact of the highest interest. Astronomers have observed thousands of spots and have invariably noted that equatorial spots move with greater rapidity than those nearer the poles; the period of rotation being 24 days 9 hours at the equator, 25 days 7 hours at a latitude of 20°, and 26 days 7 hours at a latitude of 35°. Thus the surface of the sun does not rotate as a coherent whole, as would be the case if the surface consisted of a solid crust. To realise the full meaning of this well-ascertained fact we must adduce another. The study of the variations of the magnetic needle on the earth's surface has revealed a periodicity of

approximately the same duration as the rotation of the equatorial solar zone. It is probable that this coincidence is not fortuitous and that the sun modifies the magnetism of the earth.

We have thus, from the careful observation of the spots, acquired the certitude that the bright external surface of the sun is fluid, and new reasons for considering that the same is true of the central regions; these conclusions are in complete agreement with the inferences drawn from the mean density and the temperature.

But there is still much to be learned from an attentive study of the spots; we know neither their nature nor their origin. The question has long remained an open one, for Galileo thought they were clouds floating in the solar atmosphere, and De Lalande took them for mountains, the varying steepness of whose sides produced the phenomenon of the penumbra. Derham saw in them the smoke discharged by the sun's volcanic craters, and many savants have considered them to be scoriæ floating on an ocean of fire. But since the observations made in 1774 by Wilson, corroborated by Sir William Herschel, no doubt is permissible

regarding their actual form; the spots are cavities with sloping sides pierced through the external luminous zone and opening upon a dark interior region. As a matter of fact, when a slowly changing spot of regular circular form is followed in its motion across the disc it will be seen, as it approaches the edge, to assume an oval form, then to narrow until it becomes linear. This series of appearances agrees entirely with the projection effects of a hole observed first perpendicularly and then under increasing degrees of obliquity; this observation, which has been checked repeatedly by various astronomers, compels us to discard every explanation but Wilson's.

Hitherto we have examined as a whole the light emitted by different points of the sun; we shall now analyse the complex radiations which emanate from it. As is well known, the use of the prism enables this classification to be made. Kirchhoff and Bunsen, the true creators of spectrum-analysis, invented an instrument, the spectroscope, based on this property of the prism whose employment enables us to characterise

different luminous sources by the nature of their radiations. It may not be superfluous to recapitulate briefly the truths established in the laboratory before applying them to astronomical research.

Solids or liquids in an incandescent state examined by the spectroscope give a continuous spectrum formed by all the colours of the rainbow, ranging from red to violet. Of this nature is the light emitted by the carbons of an electric arc, or by a charge of molten steel when poured from the crucible, but we find the same continuous spectrums in the flame of a candle, of a lamp, or of coal gas.

It is important that we should not lose sight of the fact that, in these flames, what gives light and gives this spectrum is a solid, consisting of particles of carbon suspended in the gaseous mass and heated by it. On the other hand, bodies which are really in a state of gas or vapour, free from more condensed elements, are characterised by the poverty of their luminous emission; their spectrum, when they are brought to a high temperature, is constituted by a certain number of very fine lines, characteristic of their chemical nature. These lines,

separated by dark intervals, occupy in the field of vision of the spectroscope well-defined situations. This property, particularly distinct in the case of hydrogen and of vapours of metals, has enabled each element to be characterised by the lines which it produces at a high temperature. Sodium, for example, gives two yellow lines very close together; hydrogen gives four principal lines, one red line very bright, one blue and two others violet; iron vapour gives an admirable spectrum, consisting of hundreds of lines.

This is not all; it is possible to identify bodies not only by the light which they emit, but also by the light which they stop, which they absorb. A red glass appears red to us, because it is opaque for all light except red. If a transparent but coloured body is interposed between a source of white light and a spectroscope, the continuous spectrum produced by the source will appear crossed by a series of broad dark bands or narrow black lines according to circumstances. The bands and lines correspond to the absent radiations absorbed by the intervening body, and the nature of the body

is revealed by them, just as the incandescent metallic vapours were revealed by their emission spectrum. Thus the atmospheric gases and water vapour, when in thick layers, are each characterised by numerous black lines.

For a long time no relation was suspected between the emission and the absorption-spectra; their study formed two separate chapters of spectroscopy, when the investigations of Foucault and of Kirchhoff established between them the following relation. The radiations emitted by an incandescent vapour are absorbed by the same vapour at a less heat. It is impossible to examine here the problems raised by this property. We shall limit ourselves to making its signification clear by recalling the characteristic experiment by means of which it is usually demonstrated. If we examine through the spectroscope the intensely bright yellow light obtained by volatilising a grain of sodium in the extremely hot flame of an enameller's lamp, it appears constituted, as we have already stated, by two yellow lines situated very close to each other. If we now interpose between this flame and the spectroscope an alcohol flame, less hot than the

former, and likewise containing sodium vapour, we shall see the two existing bright lines replaced in the same situations by two dark lines showing on the feebly-illuminated field of the spectroscope; this is the phenomenon of the *inversion of lines.*

All these properties will be of use to us in our study of the solar spectrum. In order to carry out this study an image of the sun, about twenty to twenty-five centimetres in diameter, is produced by means of a suitable combination of lenses, and is examined under the spectroscope in all its parts. Most frequently, that is to say unless the instrument is directed towards a spot or the extreme rim of the disc, the well-known spectrum of the sun is observed, that which constitutes the greater part of its radiation. It comprises the entire scale of colours from red to violet, without counting its invisible prolongations: the heat-giving or infra-red spectrum and the chemical or ultra-violet spectrum. It is, beyond doubt, the emission spectrum common to all bodies, solid or liquid, when raised to a high temperature. We are

therefore led to the conclusion that the external radiant surface of the sun, called the photosphere, contains solids or liquids, and as, on the other hand, we are equally certain that it does not form a coherent whole we can only conceive it to be formed of very tenuous particles, suspended in a gaseous mass, where they act in the same manner as the carbon dust in a candle-flame.

What is the thickness of the photosphere, and what is there inside it? The only way to get an idea of this is to look through the spots, which open like windows into the interior of the orb. Now the measurements made by Wilson and Secchi limit the mean depth of the spots to about two or three thousand kilometres, an insignificant figure compared with the dimensions of the sun; we may therefore conclude that the photosphere is a mere film on the surface of the sun. To determine the nature of the underlying layers it would be necessary to direct the spectroscope towards the centre of the spots, but the complexity of the results hitherto obtained defies analysis and justifies only the vaguest inferences. The dimness of the spectrum produced by these spots, and the presence in it

of several bright lines, agree with the hypothesis, already stated, of the gaseous state of the solar nucleus. We are compelled to be satisfied with these vague conjectures.

It is, however, possible to obtain more reliable information by turning our attention to another point. As already pointed out the sun is less luminous at the periphery than at the centre; this fact escapes every-day observation, because the excessive radiance of the sun deprives our retina of its sensibility, but it is manifested both by photography and by photometric comparisons made on a sufficiently enlarged image of the sun. In this manner the centre of the solar disc proves to be five times more luminous than the periphery; moreover, the colour of the edge of the orb is distinctly reddish. Peculiarities of this kind would be inexplicable if the sun were limited to its photosphere; they can only be explained by the existence of an absorptive atmosphere, which diminishes in a greater measure the rays emanating obliquely from the edge of the orb than those originating in the central regions. On the contrary, the moon, which has no atmosphere, appears to us

a practically flat surface, that is to say, equally illuminated throughout.

We are now brought to admit the existence of a gaseous atmosphere surrounding the photosphere, and are in a position to understand and interpret the characteristic property of the solar spectrum. This bright spectrum is not rigorously continuous; it is crossed by a multitude of black lines, occupying fixed positions; physicists have located thousands of these lines, which are evidently due to the absorption caused by the gaseous media interposed between us and the photosphere. First of all the properties of one of these media, the terrestrial atmosphere, are well known to us; in fact, we find in the solar spectrum all the absorption lines of oxygen and water vapour, with the characteristics which guarantee their origin. They are more marked when the sun is near the horizon, because its light then traverses a greater thickness of our atmosphere and, on the other hand, all the lines due to water vapour disappear in times of intense cold, that is to say, when our atmosphere is entirely free from water vapour. But in addition to these lines, called telluric lines, which cannot

teach us anything very new, there is a large number of others, perhaps two-thirds of the total number, which have necessarily an entirely different origin. Now the first spectroscopists, including Kirchhoff, discovered at an early date that nearly all these other dark lines occupy in the field of the spectroscope the identical position occupied by the bright emission lines of hydrogen and of a certain number of metallic vapours; it has thus been possible to identify 490 lines belonging to iron with the same number of dark lines belonging to the solar spectrum. Such a number of coincidences could not be due to accident, and leads us to conclude that the photosphere is surrounded by a cooler absorptive gaseous layer, containing in addition to hydrogen the vapours of numerous elements: sodium, barium, calcium, magnesium, iron, manganese, chromium, cobalt, nickel, zinc, copper, titanium, strontium, etc. That is to say, a great proportion of the materials composing our earth. We have therefore demonstrated the existence of a gaseous layer external to the photosphere, to which astronomers have given the name of *chromosphere*. We shall see, in a

later chapter, how the observation of total eclipses of the sun has enabled the solar atmosphere to be observed with the naked eye; but this exceptional method is not the only one enabling us to study it. In 1868 M. Janssen and Sir Norman Lockyer discovered simultaneously the method which has rendered possible the daily observation of the chromosphere. It consists in forming an enlarged image of the solar disc, against the edge of which is turned the slit of the spectroscope, that is to say, the narrow rectilinear opening through which the light to be analysed enters the instrument. It is a delicate experiment, because the zone to be observed forms a very thin layer around the photosphere. As long as the disc itself is examined the usual bright spectrum appears crossed by dark lines, but the moment the photosphere is left behind the image changes entirely; the field of the spectroscope becomes darkened, with the exception of a few bright lines characteristic of a gaseous mass at a high temperature. The existence of the chromosphere is thus demonstrated by a direct and decisive experiment; it only remains to deter-

mine the elements composing it, its form and dimensions.

The spectroscope gives an immediate answer to the first question; it is enough to determine the position of the bright lines emitted by the chromosphere and try to identify them with the lines of known bodies. Now, the characteristic lines of hydrogen are recognised without hesitation; their brightness and constant presence prove hydrogen to be the fundamental element of the chromosphere. To it this gaseous layer owes the red colour which suggested its name, and whose influence is visible in the reddish colouring of the sun's rim. But this influence affects the entire surface of the orb; the chromosphere resembles a red veil stretched over its disc. If we could tear it off and uncover the photosphere we should see that the latter is blue.[1] In addition to hydrogen the chromosphere is shot through, but in a more irregular

[1] It is known, as a matter of fact, that the colour of incandescent bodies changes from red to white, and then to blue, as their temperature increases; thus the electric arc at 4000° centigrade is already distinctly bluish. This blue colour must be even more marked in the case of the photosphere, whose temperature reaches 7000°.

manner, with numerous metallic vapours of magnesium, sodium, calcium, iron, chromium, etc. It contains also another element. Among the bright lines of the chromosphere a yellow line defied for a long time identification with those of the known terrestrial elements. Astronomers, abandoning the research, and having exhausted all alternative hypotheses, attributed it to an unknown body, doubtless similar to hydrogen, which they called *helium*. It has, however, since been discovered that helium exists also on our planet. Its presence has been recognised in a Greenland mineral called cleveite, in some mineral waters, and even in our atmosphere; the sum of its properties connect it with hydrogen. This is a truly remarkable instance of the certainty of spectroscopic methods.

The chromosphere does not form a uniform layer. It is interesting to determine its distribution. The most elegant solution of the problem has been supplied by the spectroscope, which was certainly not intended for such a purpose. This solution was first pointed out by Huggins, and has since been employed by all astronomers. When the slit of the spectroscope,

sufficiently opened, is brought to bear tangentially on the edge of the sun's image, an image of the corresponding part of the chromosphere appears in the field of the instrument. This image is formed at the place where with a narrow slit the red line characteristic of hydrogen would have appeared. The chromosphere is invisible to us, under ordinary conditions, because the blinding light of the photosphere overwhelms its very feeble lustre, with the exception of this red radiation, but the spectroscope relegates each radiation to its own proper place and enables the chromosphere to be observed by the most suitable light.

The method of observation, discovered by Huggins, has rendered it possible to explore systematically the chromosphere, and this layer of the sun is now known in detail. We know that its mean depth is very limited, about eight thousand kilometres, and augments the diameter of the sun by only one hundred and seventy fifth part. Moulded internally on the photosphere, its external face presents forms of extraordinary irregularity and variety. In places it is as flat as the sea; in others it is covered with luminous filaments, like bright hairs all pointing

in one direction, at least at the same time and in the same region. Elsewhere it towers above the general level in monstrous heaps called *protuberances*.

These protuberances take the most diverse forms, and an attempt has been made to distinguish them by the names of *heaps*, *jets*, and *plumes*; but what strikes the observer most forcibly is the ceaseless agitation stirring the entire gaseous mass and projecting it, during movements of violent eruption, to a height of several hundred thousand kilometres, at speeds reaching, and even exceeding, two hundred kilometres per second.

The following observation of Secchi may serve as an example:

"On October the 16th 1871, at ten minutes past nine o'clock, the western part of the sun did not present any remarkable feature. At 9.30 a very intense conical flame became visible towards the west at 85° from the pole; near by, at a distance of about 5°, was a large and diffuse cumulus; at 9.36 the height and width of the flame had doubled, and this cumulus appeared to have been absorbed by it. At 9.43 all had

changed; the flame had become fan-shaped and formed of very bright jets, terminated at their tips by tongues of fire. At 9.49 there was a considerable extension in width and height, forming a movable sheaf of fireworks. On the left an enormous mass of parabolic rays was to be seen falling back on to the sun. Some bright masses, suspended above and completely isolated from the chromosphere, looked like rockets which had just burst. At 9.56 these masses still continued to rise, but the light was decreasing; three principal jets could be distinguished. Several tongues of fire formed from broken streamers remained isolated in the upper regions; the maximum height of the vertical jet was about ten diameters of the earth. At ten minutes past ten all was finished, leaving nothing but two little flames, and nothing fresh occurred during the remainder of the day."

Thus the eruptions betray the activity of the chromosphere, whereas agitations of the photosphere are manifested by variations of the spots and faculæ. It is natural to inquire whether these two phenomena are not due to a single cause. It was remarked long ago that both

occur principally in the sun's equatorial zone, and that periods of great spot frequency are also characterised by great disturbance of the chromosphere. It is, in general, difficult to compare the spots, which are visible on the surface of the disc, with the protuberances which are only observed at the periphery; however, it is now certain that both are in general simply two aspects of a single disturbance. When we observe a violent eruption at some point of the eastern edge of the sun we are practically certain to discover on the following day a sun spot at the place to which the point has been transported by the sun's rotation. Conversely a spot of variable and tumultuous form, when it reaches the western edge of the orb, is betrayed by the upheaval of the chromosphere. It is also noticed that the faculæ, which are apparently elevated regions of the photosphere, seem to coincide with uprushes of practically pure hydrogen; whereas the eruptions which cover the spots would appear, from spectroscopic examination, to consist of hydrogen shot through with numerous metallic vapours.

Our knowledge might have remained limited

to the chromosphere and the protuberances if total eclipses of the sun had not realised before our eyes a gigantic experiment. By interposing, from time to time, the moon as a screen between us and the sun's disc Nature protects us for a moment against the radiance of the photosphere and enables us to observe the zones surrounding it. On such occasions the protuberances of the chromosphere become visible to the naked eye, but the light does not cease suddenly outside this layer. A continuous and gradually-decreasing glow extends around the sun to a greater thickness than the diameter of the photosphere, constituting what is called the corona. This glow is not exactly concentric to the orb; it is narrower in the polar regions and much broader opposite the protuberances. Observed through the spectroscope it gives a double spectrum, formed, on one hand, by a continuous light extending from red to blue, and on the other by bright, separate lines. These lines prove the corona to be self-luminous, and on examination they prove the existence of various bodies, chief amongst which is hydrogen. The continuous spectrum, on the other hand, proves the existence

of an attenuated solid dust, which sends out light to us, either by direct emission or by diffusing light received from the photosphere.

The study of the corona constitutes at times of total eclipse one of the principal occupations of physicists and astronomers; we shall have occasion to consider it more in detail in a future chapter. Enough has, however, already been said to give a summary idea of the general constitution of the sun; we look on it as a fluid, and probably, almost entirely, gaseous mass, animated with a rotary motion, whose speed decreases from the centre towards the peripheral zone, and raised to a very high temperature, varying in general in a similar manner to the speed. Possibly such bodies as gold and platinum, which have the highest vapour-densities, are concentrated towards the centre, while the lightest bodies, such as hydrogen and sodium, are arranged towards the periphery; this would explain the absence of any lines characteristic of the heavy metals in spectroscopic observations of the surface-zone. None but isolated elements could exist in the nucleus owing to its elevated temperature; but cease-

less uprushes, doubtless due to variations of temperature, combined with other causes, carry the constituents of the deeper regions into a cooler space, the zone of chemical reactions, or photosphere. In this zone lime, magnesia and carbon are doubtless formed in impalpable powders, and perhaps the refractory metals condense for an instant, forming tiny incandescent drops; then everything falls back into the superheated abyss of the interior to be volatilised, until a fresh convulsion brings them back into the photosphere.

These eruptions of central matter attain in places sufficient development and violence to pierce the photosphere, and we can then see through the burning mass of projected gas the dark depths of the nucleus; frequently a spot formed in this manner is rendered more permanent and regular by the action of vortical movements; in other cases the hole closes after the eruption, and the continuity of the photosphere is restored. But even irrespective of spots, the surface is never at rest. Its granulations prove its irregularity, and the faculæ constitute more extended swellings, at times

sufficiently high to traverse the chromospheric layer. This layer, whose temperature is one or two thousand degrees lower than the photosphere, is constantly disturbed by the agitation of the underlying layers, and the hydrogen of which it chiefly consists is being constantly invaded by metallic vapours, which escape through all the pores of the photosphere. It is surrounded in its turn by the corona, a mixture of hydrogen and other gases, and of incandescent dust, which decrease gradually in temperature and density as they reach out into interplanetary space.

Such is roughly the idea which we can at present form of the "globe of fire" that guides and heats the procession of the planets. Perhaps little will be left in a century of all our theories, because the solar problem is being investigated with great energy. What is more, every new thing found in the heavens checks and enriches the discoveries already made concerning the sun; it is, after all, a star like all the others, one of the billions of bright points scintillating in the sky; astronomy has taught

us that there is nothing in its size, its position or its motions to constitute it a world apart; and spectrum analysis has confirmed these conclusions by showing us that the same elements are found in all the stars; it is therefore legitimate to seek from the nebulæ an idea of the sun's past, and even to attempt to forecast its future from the present state of the extinct stars which wander over the pathway of the heavens.

ECLIPSES

The work of an astronomer is anything but monotonous; every day, but chiefly every night, the sky changes its appearance and lends itself to new observations and measurements. But it is principally for eclipses of the sun that greatest preparations are made. Then, many months ahead, physicists and astronomers prepare their plan of battle and complete all their arrangements for making the best use of the few minutes during which the occultation lasts; then, when the time arrives, they do not hesitate to leave the peace of their laboratories to place themselves under the most favourable conditions for their observations; and the great civilised nations, however pressed they may be for money, always find in their treasuries the requisite funds for these enterprises.

The necessity for the concentration of so many workers on a single task is due to the

infrequence and short duration of eclipses. If the moon circled round the earth in the plane described by the latter in its yearly rotation round the sun, every full moon would be accompanied by an eclipse of the moon and every new moon by an eclipse of the sun.

This is nearly the case, since the plane of the lunar orbit is inclined only five degrees to the plane of the ecliptic; but this slight inclination is sufficient to upset everything, because it makes the possibility of an eclipse depend on a somewhat rare coincidence; the eclipse is only possible if at full or new moon our satellite is crossing the plane of the terrestrial orbit, which then justifies its name of ecliptic.

And this condition, necessary because it places the three bodies in a straight line, is not even sufficient. As a matter of fact, if, in the case of lunar eclipses, we calculate from the distance between the earth and the sun and the diameter of these two globes the length of the cone of shadow thrown by the earth, we find that it is at least 210 terrestrial radii long; as the moon is only about sixty terrestrial radii distant from our globe she should necessarily

enter the shadow-cone whenever the above conditions are realised.

However, what happens is less simple, owing to the refraction caused by our atmosphere, which acts on the solar rays as a regular convergent lens. The summit of the shadow-cone is thus thrown back to forty-two radii, instead of 210; consequently a complete eclipse of any part of the moon is impossible. All that can happen is a decrease of brightness, because the sun is never hidden in its entirety from any point of our satellite. An observer placed on the moon, and looking at the phenomenon which constitutes for us an eclipse of the moon, but for him an eclipse of the sun, would still see, at the most favourable moment, three-quarters of the sun's disc. On the other hand, as the terrestrial atmosphere absorbs chiefly the blue and violet rays, our observer would receive only red light, such as the sun sends us at his setting; this is the reason why the moon, which only shines with borrowed light, appears red during eclipses.

In the case of eclipses of the sun the conditions are different; the distance from the earth to

the moon varies between fifty-five and sixty-two terrestrial radii; on the other hand, the length of the shadow-cone thrown by the moon varies between fifty-seven and sixty terrestrial radii and is not reduced by any refraction, as there is no lunar atmosphere; it follows that this cone may or may not reach the earth, and that therefore an eclipse need not necessarily be total. Let us suppose the favourable conditions to be realised; then if a giant wandering through the worlds could observe what is happening he would see the cone of shadow, sweeping behind the moon, strike the earth and mark on its surface a circular black spot, some 200 kilometres in diameter, which travels with extreme rapidity in the general direction from west to east. This spot, which no sunlight penetrates, is itself surrounded by a more extensive zone, in which the light decreases progressively from the interior towards the edges; this is the zone of penumbra, illuminated by a variable portion of the solar disc. As a matter of fact, an observer in a balloon, or on a high mountain, sees quite clearly the moving cone formed by the lunar shadow as it advances like a dark and threatening

storm and invades the plain with a speed of nearly one kilometre per second.

We have said that for a total eclipse it is necessary that the length of the cone formed by the moon's shadow should exceed the distance separating us from the moon; if, as frequently happens, this condition is not fulfilled the eclipse will be only annular in the most favoured regions; in such cases the solar disc will, even at the most favourable moment, project all round the moon, and darkness will never be complete.

All these phenomena can be predicted without difficulty by astronomers, because the movements of the heavenly bodies are known with the greatest precision. At present the predictions of the ephemeridæ are given to the tenth of a second, but this degree of approximation has only been obtained gradually and by an increasingly accurate knowledge of the constants of the solar system. At the commencement of the nineteenth century eclipses were foretold with an approximation of only several seconds; a hundred years earlier La Hire's tables contained errors of 4 to 5 minutes, and before the appearance of these tables the pre-

cision was still less; the case of the eclipse of 1684 may be cited, because although it had been announced to be total at Rome only three-quarters of the sun were actually hidden.

But ages before Kepler and Newton experience had enabled approximate rules to be framed. Thus it is related that Sulpicius Gallas, a lieutenant of Æmilius Paulus, succeeded in preventing a mutiny of his army by predicting an eclipse of the moon. These astronomical notions seem to owe their origin to the Eastern races; the Chaldeans had noticed that eclipses recur at regular intervals. This *Chaldean period*, called also *Saros*, of eighteen years eleven days' duration, does, as a fact, restore the sun, the earth and the moon to the same relative positions. It contains seventy-five eclipses—forty-six of the sun [1] and twenty-nine of the moon.

[1] Not forty-one, as the most recent writers state owing to a mistake, whose cause is sufficiently original to be mentioned. Halley, having made a table of the eclipses belonging to a Chaldean period, printed them on two consecutive pages of his *Treatise of Astronomy*; but as he could only find room on the first page for forty-one solar eclipses, and on the second page for the twenty-nine lunar eclipses, he relegated the five remaining solar eclipses to a note, which must have escaped the attention of the first author who borrowed these figures, and all subsequent books have reproduced this singular error.

These figures may at first sight seem paradoxical, as we know from our experience that opportunities are much more frequent for observing eclipses of the moon than of the sun; but we must not forget that when the moon is eclipsed the phenomenon is visible at all points of a terrestrial hemisphere, whereas, in order to observe a total eclipse of the sun, it is necessary to be within the narrow strip traversed by the moving spot; thus the last total solar eclipse visible in Paris dates as far back as 1724, and the next following one will not occur before 2026.

It would, however, be a mistake to conclude that all total eclipses are equally interesting to science; they may be more or less accessible for observation. Frequently the zone of visibility crosses oceans, regions where the sky is perpetually clouded, or practically inaccessible deserts; and finally the duration of the occultation varies from one eclipse to another, the maximum being eight minutes at the equator and six minutes at the latitude of Paris. Let us consider, as an example, one of the latest

eclipses, that of 30th August 1905, which was observed in France as a partial eclipse. It appeared under the most favourable conditions. Firstly, owing to the geographical position of the countries crossed; starting from North America and moving in the general direction from north-west to south-east, the circle of total umbra swept diagonally across Labrador, the Atlantic, Spain, the Balearic Isles, Algeria, Tunis, Tripoli, Egypt, where it passed near Assouan; it crossed the Red Sea and part of Arabia, after which the travelling shadow lost touch with our planet, which it had crossed in its course during only two hours, forty-eight minutes. A long line of suitable stations, from Spain to Egypt, was thus available for the observers, a condition of great importance, considering the weight, the number and the delicacy of the instruments having to be transported to the sites selected. On the other hand, the season and the geographical position of the regions traversed justified the hope of clear skies, without which observations are impossible.

The totality of the eclipse is reached at different times at successive points of the zone, and observers were obliged to establish their observatories along the centre line and not near the edges of the strip, because there the eclipse is of maximum duration, varying from 2 minutes, 28 seconds in Labrador to 3 minutes, 45 seconds in Spain.

The previous total eclipse of 28th May 1900 had a duration of only 1 minute, 19 seconds; thus the eclipse of 1905 presented much more favourable conditions, enabling photographs to be taken with the prolonged exposure necessary for bringing out all the details of the external corona. In addition, the longest eclipses are also those in which the sun is most completely hidden by the moon's disc, so that less light from the photosphere is, in such cases, mingled with the actual light of the corona. Spectroscopic investigation is greatly facilitated by this condition.

The eclipse of 1905 was also specially interesting for another reason. The observation of solar spots, which has been attentively pursued for a hundred and fifty years, has

supplied evidence of a periodic law which remains entirely unexplained, though it is unmistakable. Every eleven years, roughly, the activity of the sun reaches a maximum. Now the eclipse of 1900 took place during a period of quiescence; 1905, on the contrary, was a year of great agitation, and consequently all the phenomena connected with this increased solar perturbation, such as the protuberances and the development of the gaseous corona, were expected to be present in especially favourable conditions for examination. All these details show that each eclipse has a special physiognomy of its own, and facilitates in greater or less degree the solution of the many solar problems.

Many have been the descriptions of the striking appearance presented by Nature during a total eclipse of the sun; but we shall mention here only the facts suitable for scientific study.

A few seconds before totality the visible part of the sun forms a crescent, which decreases with surprising rapidity; it is soon reduced to a mere thread, split into separate lengths by the

protuberances of the lunar contour, like a string of beads; then the sun disappears. "Immediately," says Father Secchi, "the scene changes in a sudden and complete manner; in the midst of a lead-coloured sky stands out a perfectly black disc, surrounded by a magnificent glory of silvery rays, among which scintillate rose-coloured flames." The stars, and the planet Venus, shine in the sky, but the general darkness is far from being complete; some light is emitted both from the bright corona which surrounds the moon and from the regions of the terrestrial atmosphere situated outside the cone of umbra. It is possible, with difficulty, to read a book printed in large type, but it is almost impossible to tell the hour on a watch, and observers are obliged to keep lighted lamps near their instruments in order to be able to read their scales.

The irradiation surrounding the dark disc of the moon occupies an expanse of the sky which varies considerably from one eclipse to another, but it is generally more or less equal to that of the sun itself. First, reddish masses are to be seen, distributed irregularly around the solar disc, and situated principally in the

equatorial zone of the orb, that is to say, in the region of its surface most remote from the axis around which it turns. These are the *protuberances* which had been revealed to the learned world by the observation of eclipses before the spectroscopic method of Janssen and Lockyer enabled them to be studied in a continuous and systematic manner. Beyond stretches the *corona*. It is difficult to estimate the total luminosity of this corona, owing to the great variations of light which accompany the very short phenomenon of the eclipse; it has, however, been compared to that of the full moon.

We are able to distinguish in the corona two different regions—the *internal corona* of a silvery white colour, on which stand out the reddish projections of the protuberances; then, all around, a less bright region, often called the *halo*, because its appearance recalls the luminous circle that painters draw round the heads of their saints. The halo seems to consist of long plumes, some straight and some bent. It is, however, worthy of note that whereas the protuberances and the photosphere itself are in

a state of ceaseless agitation, the corona, on the contrary, remains invariable throughout the duration of the eclipse; it leaves, as the astronomer Young said, the impression of a calm and serene immobility.

Such is, in its main lines, the spectacle offered to our contemplation with the naked eye or through a telescope during the totality of the eclipse. On the reappearance of the sun the phenomena are repeated in inverse order, but as the eye has become accustomed to the darkness they are more readily noticed; the jagged rose-coloured edge of the chromosphere and of the protuberances is distinguished more clearly and the corona remains visible for a minute after the eclipse has ceased to be total; then the light reappears gradually, and the irradiation of the photosphere extinguishes the glow of the less brilliant parts.

But those who, turning away from the spectacle in the sky, observed what was happening on the earth, might have witnessed a strange phenomenon which has remained inexplicable. Arago describes it as follows: "At the moment when the eclipse was on the point of becoming

total I saw the last rays of the sun undulating violently and rapidly on the white wall of one of the military buildings of the Saint-Dominic rampart. The effect was similar to what we observe when the sun's light falls on a wall or a ceiling after having been reflected from the surface of a disturbed sheet of water. The identical phenomenon was repeated at the moment of the sun's emergence; the undulations, which at first were strong, gradually decreased, and then disappeared at the end of five or six seconds." These undulations have been seen since, during every eclipse, by numerous observers; drawings have even been made of them, but their origin remains as mysterious as ever.

It is evident that at no time could so marvellous a phenomenon as a total eclipse remain unnoticed. The ancients had recognised the existence of the corona, and Plutarch tells us that the moon, during an eclipse, "always allows a glow to escape around its rim, which does not permit the darkness to become perfectly black and profound." Even more precise observations of the same nature were made during the Middle

Ages. They were then accounted for in the most natural manner by admitting that the moon did not entirely cover the solar disc, and this interpretation prevailed until it became possible, by the use of the telescope, to measure angles accurately. It was then placed beyond doubt that in some eclipses the apparent diameter of the moon distinctly exceeds that of the photosphere.

Some other explanation was therefore required. Kepler, with the intuition of genius, suggested the existence of an atmosphere of inflamed ether near the sun; but he soon joined all the astronomers of the time in adopting the hypothesis of a lunar atmosphere, illuminated, from behind by the sun, during an eclipse, in such a manner as to form the corona. This opinion was still supported in the eighteenth century by a distinguished astronomer, Louville, who was commissioned by the Academy of Sciences to observe at London the eclipse of 1715. Louville fancied he noticed that the plumes of the halo followed the direction of the rays of the moon and not of the sun; and carried away by his hypothesis, to which he attempted to connect

all the facts observed, he attributed a thickness of sixty-four leagues to the lunar atmosphere. But the absence of any gaseous layer around the moon, is now, and has long been, beyond dispute; it is sufficient to follow the course of the stars when they pass near our satellite to realise, with all the precision of astronomical measurement, that the trajectory of their rays is not in the slightest degree deviated, as it would be by an atmosphere, were it ever so shallow or attenuated; and the distinctness of the umbra in eclipses of the sun is sufficient to prove beyond doubt the absence of any gaseous layer around our satellite.

At the time when Louville was bringing forward the "air of the moon," other astronomers thought the corona might be attributed to a diffraction-phenomenon. Luminous rays are not propagated rigorously in straight lines, but when they meet an obstacle the separation of light and shadow is less distinct than would be imagined from geometrical optics; this property of light explains the following experiment carried out in 1715 by Delille. A pencil of sunlight was admitted into a camera obscura

through a small hole drilled through one of its sides and suitably widened on the inside, throwing an image of the sun on to the opposite side of the camera; when a small lead disc, slightly larger than the pencil of light, was interposed between the image of the sun and the hole, its shadow covered the image and appeared surrounded by a graduated ring of weak light. This was naturally looked on as an image of what occurs in the case of an eclipse; the assumption that the irregularities of the lunar disc allow more light to pass where they are sunken and less where they project, accounted for the irregularities of the corona and for the glories radiating around it.

This hypothesis of diffraction is not more acceptable than that of a lunar atmosphere; the phenomena adduced by Delille actually exist, but their laws, which to-day are perfectly well known, could not in any way account for the corona or for the protuberances. However, the eighteenth century was satisfied with the two explanations we have mentioned. Science had not, at that time, acquired the habit of rigorous criticism which, during the past century, has ensured its

progress. It was looked upon as a pastime suitable for the idle. It is nevertheless true that the two total eclipses of 1715 and 1724, both visible in France, awakened the deepest curiosity. Both were observed by the King, surrounded by the astronomers of the Academy. In 1724 Louis XV. summoned Maraldi and Cassini to the Trianon, and had the thermometer and the barometer brought from his room in order to observe "the variations which might take place during the eclipse, both in the degree of heat and in the weight of the air." It is not difficult to imagine what sort of results could be obtained under such conditions.

Matters remained practically in this condition until 1842. The eclipses of 1748 and 1806 were the occasions of fairly accurate descriptions of the phenomena, but it was impossible to link them up with the general laws of Nature, because the science of physics was still unborn. On the occasion of the eclipse of 1842, a man, whose scientific influence was then universally recognised — François Arago — published in the *Annuaire du Bureau des Longitudes* what was really an appeal to the scientific world. Arago

had the intuition that the time had come for studying the worlds, not only with the eyes of the astronomer but also from the physical point of view. And at that time physics, thanks to the impulse of Gay-Lussac, Cavendish, Faraday, Fresnel and of a band of scientists, unequalled in any other age, had just established its fundamental law. The nature of light was known, and that was the main point, as light forms our sole means of communication with the ultra-mundane regions. Photography had just been discovered, and spectroscopy was on the point of being created by the strenuous efforts of Kirchhoff and Bunsen. But above all the habit of method and of scientific procedure had been learned, which rejects approximations and demands precise verification.

As a matter of fact it is from the eclipse of the 8th July 1842 that the true progress of solar astronomy dates. Observed in France, Italy and Austria by Airy Arago, Bailey and Fusinieri, it enabled a clean sweep to be made of all the hypotheses which the eighteenth century had been unable to criticise; henceforth there could be no question of the effects of diffraction, or of a

lunar atmosphere; it was universally accepted that the appearances observed are caused by the sun itself, and that, in Arago's words, "we are on the track of a third envelope situated above the photosphere and consisting of dark or feebly luminous clouds."

From this date every successive eclipse, studied by numerous and well-equipped expeditions, has contributed new results to science. From 1860 the use of photography, due to Warren de la Rue and to Secchi, has rendered possible a precise comparative study of the protuberances and of the corona observed from different stations and consequently at different moments. The eclipse of the 8th August 1868 marked the general application of spectroscopy to the chemical analysis of the chromosphere and of the protuberances, but it was also distinguished by a most important discovery. M. Janssen was at Guntoor, in India, in order to observe the spectrum lines of the protuberances; having been struck by the brilliant brightness of these lines, it occurred to him that they might perhaps be visible by daylight. The day following, by directing the opening of his spectroscope

along the periphery of the sun, he had the satisfaction of perceiving the bright rays of the protuberances. From that day the study of solar eruptions ceased to be at the mercy of eclipses; it could be carried out in any situation wherever the sun was visible. However, we must not forget that only the most intense radiations, such as those of hydrogen and helium, are suited for these daily observations. The multitude of less bright rays of the chromosphere and of the protuberances, especially those situated in the violet and the ultra-violet, can only be observed on the occasion of an eclipse.

From the time of M. Janssen's discovery the observations made during eclipses have been concentrated on the corona, because owing to its feeble brightness the corona evades daily observation, its weak radiance being drowned by the intense light of the photosphere diffused by our atmosphere.

Let us see what the succession of eclipses has taught us on this subject.

The corona appears to consist of two distinct parts which interpenetrate each other more or

less and are independent in their evolution. One of these parts is entirely gaseous; it appears to form around the sun an atmosphere regular in form, but flattened towards the poles, and its luminous emission, seen through the spectroscope, is characterised by numerous bright lines. A photograph obtained in Spain during the last eclipse showed over one hundred and twenty of them, including the lines of hydrogen, helium, titanium, iron and magnesium. But the spectrum of the corona is further distinguished by a radiation of its own; it is a very bright green line, which puzzled all observers, because they were unable to assign it to any known body. This line is considered to characterise a new body, *coronium*, and as the coronium line is frequently observed in the higher regions of the solar atmosphere, where even hydrogen lines cease to be visible, one is inclined to believe that this hypothetical body is a gas still lighter than hydrogen. The gaseous corona would thus consist of three principal gases—hydrogen, helium and coronium — shot through with metallic vapours.

The study of the bright rays of the gaseous

corona supplies another valuable piece of information; it has revealed the rotation of this atmosphere. We saw in the last chapter how the displacement of the lines, when the eastern and the western edges of the sun are viewed in succession, enabled us to infer the rotation of the photosphere. Applied by M. Deslandres to the lines of the corona, this method has led to interesting results, by showing that the gaseous corona turns in the same direction as the photosphere, and with a speed of the same order of magnitude.

Finally, direct observation, completed by photography, has revealed a very important law of variations. At periods of maximum solar activity the gaseous corona has a much greater extension than during a minimum. Thus in 1874, a year near a maximum, the line of coronium was visible at an angular distance of over forty-five minutes from the edges of the photosphere, whereas in 1878, during a minimum, it could not be seen beyond fifteen minutes, and in the eclipse of 1900, when the solar activity was also very weak, it could only be distinguished five minutes from the edge. In 1905, on the

contrary, the very great activity of the sun corresponded with a greater extension of the gaseous corona.

Is this variation connected with a change of the actual gaseous mass or simply with a modification of its luminosity? It is difficult to accept the first hypothesis in consideration of the enormous quantity of gas which would have to be ejected by the central regions during periods of solar activity to be reabsorbed during quiescence. Scientists have therefore adopted the second, for the time being, but even then there are many divergences of theory. Some consider the gaseous corona to be a mass heated to a high temperature, probably something like three thousand degrees, and luminous owing to its high temperature; others fall back upon electrical phenomena for an explanation. It is probable that the internal agitation of these bodies of gas is either the cause or the effect of electrical actions, of which the storms of our atmosphere can suggest but a very poor idea. It is, in any case, reasonable to suppose that these solar storms are most powerful during periods of maximum activity and are accom-

panied by a stronger and more extensive illumination of the corona.

What then can be the mechanism of this illumination? Is the atmosphere of the corona to be likened to the attenuated gases in the Geissler tube which are rendered luminous by the action of electric discharges? Can these electric discharges be Hertzian waves, like those used in wireless telegraphy, but incomparably more powerful? All these problems will no doubt some day find their answer, especially if, by any means, it were proved that radiations of an electrical nature reach our atmosphere from the sun. From this particular point of view the question of the solar corona is connected with that of the aurora borealis and with the sudden variations of terrestrial magnetism, and perhaps at some future time one and the same explanation may be found to apply to these three orders of phenomena and thus demonstrate the close interdependence of all parts of the solar system.

But the gaseous atmosphere of the corona is not the part which is most visible during

total eclipses. What chiefly attracts our attention are the radiating plumes of the halo; these plumes give in the spectroscope a continuous spectrum, which appears to have a double origin. In the regions most remote from the sun this spectrum appears identical with the spectrum of the photosphere, showing, like it, black lines on a continuously coloured ground, shading from red to violet; but, as the chromosphere is approached, the spectrum of the halo becomes brighter, while the black lines become narrow. This fact suggests that the halo consists of solid dust, which sends light to us in two distinct ways; first, it diffuses into space in all directions the radiations received from the photosphere and thus produces the dark line spectrum, and, secondly, it emits light directly, as in the case of incandescent solid bodies, that is to say, in the form of a continuous spectrum free from lines. The predominance, according to the region observed, of emitted light or of diffused light explains the effects actually observed.

What causes these solid incandescent dusts to remain at such great distances from the sun?

This is a question which confronts all who study problems of solar physics. As early as 1871 Young had shown that the spectrum and the shape of the coronal rays are quite comparable to those presented by the tail of comets. This analogy has since been confirmed by numerous observations. Now it has long been known that the tails of comets are invariably averted from the sun, which proves that the luminary exercises a repulsion on the cosmic matter composing the tail. It seems reasonable to admit that the same repulsive force acts on the solid dusts of the corona, balancing their weight, and thus enabling them to shoot to a great distance from their centre of attraction.

If this hypothesis were founded on fact we should have to explain the origin of this repulsive force. Electrical actions have naturally been suggested, but a force of an entirely different origin has also been put forward. About twenty years ago Maxwell and then Bartoli showed that light or heat radiations falling on a body which absorbs them must necessarily repel it. This action, originally predicted from theoretical considerations, is

extremely feeble under ordinary conditions; it has, however, been observed and measured by means of very delicate experiments, which fully confirmed the opinions expressed by Maxwell. It is therefore natural to admit that the intense radiation of the photosphere repels the cosmic dust forming the solar halo and the tail of comets, and this view presents the advantage of affording a simple explanation of some of the appearances observed. It has been established, first of all, that in contrast to what happens with the gaseous corona the development of the halo is greater during periods of solar quiescence. Now these periods of quiescence, during which sun spots are few and small, appear also to coincide with maxima of radiation from the photosphere, and consequently with maxima of the repulsive action of this radiation on the coronal dust. Moreover, the plumes of the halo are not directed along radii of the sun; they seem to shoot off from the polar axis around which the entire solar mass turns, and to bend towards the equatorial zone, where they spread in long streamers. This disposition appears to be due to the centrifugal force,

developed by the general rotation of the sun, which, acting perpendicularly to the polar axis, must necessarily tend to incline the coronal rays in its own direction and to increase their length in the equatorial regions, where it acts with greater intensity.

So the observed facts are woven into a web of hypothesis—a web still very delicate, which the smallest adverse fact will destroy. But that is of little consequence. The very men who have imagined these hypotheses are the first to wish them controlled by facts. It is therefore clear why each eclipse of the sun is awaited with such impatience, and why such careful preparations are made for observing it. It is no mere repetition of determinations already carried out, but it enables the facts to be observed in the light of new hypotheses. They are then either condemned without appeal or provisionally confirmed until future eclipses give an opportunity of submitting them to new tests, and of gaining precision regarding their various points.

Thus, little by little, the harvest of new facts drives back the undefined zone which

separates known and scientifically-classified things from the vast expanse of the unknown. In this border zone the progress of science is possible only thanks to fragile and temporary, hypothetical structures; but the work of the scientist in this region is more active and more profitable than in any other, for, to use the words of Duclaux, "It is because science is sure of nothing that it is always advancing."

THE MILKY WAY

ASTRONOMY is the most beautiful of all the sciences, but its beauties are hidden; mathemathics shroud it with a veil too thick for most. What astronomy deigns to reveal forms the subject of cosmography, but, being restricted to the study of the solar system, cosmography sees in the stars only the motionless sentinels watching over the paths of the heavens, and tells us nothing about their transformations, nor does it show us that they form an army with a unity and a life of its own. Teaching has its necessary limitations, nevertheless, under the pretext of symplifying the exposition, we ought not to be left with the idea that our solar system is the only organised and animated system in the world. This is doubly necessary, because our experience seems to prove the contrary. At first sight the most utter disorder appears to prevail in our universe; the constellations, with their ridiculous names and

queer forms, into which the sky has been divided up only betray our inability to unravel its chaos, which grows more inextricable as we look deeper into it.

There are about six thousand stars visible to the naked eye—those, namely, which are classified in the first six orders of magnitude.[1] Good telescopes enable us to see stars down to the eleventh magnitude and show several million stars in the sky. Herschel's celebrated telescope, the most powerful instrument ever constructed, enabled one to see a distance of a thousand million diameters of the terrestrial

[1] The magnitude of two stars is said to differ by one magnitude when the ratio of their luminous intensities, seen from the earth, is 2.5. Thus stars of the second magnitude are two and a half times as bright as stars of the third magnitude and two and a half times less bright than those of the first magnitude. It is possible to prolong this scale of magnitudes on both sides by the use of negative numbers. Thus Aldebaran, in the constellation Taurus, being selected to define the first magnitude, the small star 70 of the Whale, which can barely be distinguished by the naked eye, would be of the sixth magnitude; Vega of the Lyre, which is brighter than Aldebaran, would be characterised by 0.2, Arcturus by the cipher 0, and Sirius, which is still brighter, becomes of the—1.4th magnitude. The sun, measured on the same scale, would be a star of—27th magnitude, *i.e.*, it sends us seventy thousand million times as much light as Vega.

orbit, and revealed stars whose light takes more than two thousand years to reach us. With this instrument the firmament appeared peopled with thousands of millions of stars.

In the midst of this swarm of worlds the Milky Way alone gives us an impression of continuity; though its long whitish trail, which stretches round the heavens, presents great variations of size, for its apparent width is in places four times as great as in others, and it separates into two branches for a third of its length. But its continuity is only an illusion. Seen with the telescope it resolves itself into myriads of stars more or less densely packed together. However, its median line forms practically a great circle of the celestial sphere, at an angle of 60 with our equator, called the *galactic circle;* thus the Milky Way appears to us as an immense ring encircling our world and apparently alone representing order in the chaos of the universe.

In reality it represents order more than would appear from a superficial examination. In order to understand the true *rôle* of the

Milky Way it is necessary to abandon the old idea of a spherical firmament, studded with stars, and with the earth for its centre; the true position of each star must be defined, not only by its direction but also by its distance from the earth.

The method for determining the distance of inaccessible objects is very simple in principle; it consists in sighting the object from two different points of view and measuring the angle of the two lines of vision. This angle, called the parallax, is greater according as the object is nearer, and according as the base, that is to say the distance between the two points, is greater. This is in fact the very method which we instinctively apply in binocular vision, taking the distance between our eyes for base. But the farther away the point to be determined is, the greater must the base be if the parallax obtained is to be measurable; in order to determine stellar distances, which we know beforehand to be enormous, no base could be too great. Fortunately the earth, in its annual revolution, supplies us with the necessary stations, and all that is

necessary is to sight the star at both extremities of the earth's annual orbit, which are situated three hundred million kilometres apart.

Notwithstanding the dimensions of this base the efforts of astronomers, from Tycho-Brahe to the middle of the nineteenth century, could not remove a disquieting uncertainty with regard to the value and to the very existence of the stellar parallaxes, because the numbers found were so small that it was possible to attribute them to inevitable errors of measurement. But fortunately a method exists, already pointed out by Galileo and applied for the first time by Struve in 1835, which enables the measurements to be made with greater exactness and consequently removes all doubts.

Let us consider the group formed by a bright star and by two or three feebler ones, which seem to surround it closely. There will be a presumption, even though we may know nothing certain regarding their distance from the earth, that the bright star is nearer to us and that the others are much farther removed. Starting from this hypothesis, we may infer that the small stars, whose parallax is negligible,

will appear to us fixed in the sky while the earth is describing its orbit, whereas the nearest star will appear to have moved. We should be therefore able to ascertain for this star an annual oscillation with respect to the small stars. It is, in fact, easy to measure the small angular distance of these adjacent stars: a micrometric screw, enabling the reticule of the telescope to be brought into contact with the stars under consideration, will give their angular distance with an approximation of two or three hundredths of a second. The same degree of precision may be obtained by direct measurements from photographs of the group of stars in question.

Struve, followed by Bessel, developed the details of this method, and to-day the parallaxes of more than fifty stars are known; the precision of these measurements has, in fact, reached such a degree that Kapteyn, the Groningen astronomer, considers it possible to determine the parallaxes of the eight hundred thousand stars contained between the first and the tenth magnitude. We give here, as examples, a few of these parallaxes, with the dis-

tances deduced of the stars from the solar group. This distance is, however, not given in ordinary units; an incalculable number of ciphers would be required to express it even in millions of kilometres. The unit adopted is the light-year, that is to say the distance travelled by light, at the rate of 300,000 kilometres per second, in one year, or, roughly, ten trillion kilometres:

Star.	Magnitude.	Parallax.	Light-years.
Sirius	− 1.4	0".39	8
Arcturus	0	0".02	163
Centaur	0.7	0".75	4
Aldebaran	1	0".52	6
Polar Star	1.15	0".07	47
η Cassiopæa	3.6	0".15	22
85 Pegasi	5.8	0".05	63

Our knowledge of the parallaxes of stars enables us also to form a sufficiently approximate idea of the actual dimensions of the stars. If, for example, we imagine our sun removed to the distance at which Sirius is situated, it will be easy to calculate the amount of light sent to us from its new position. As the sun and Sirius are comparable stars, giving the same

spectrum, it is reasonable to infer that an equal surface of each emits the same quantity of light; consequently the amount of light received from these two stars, when placed at the same distance, must be proportional to their surfaces; we are therefore able to calculate the first and to measure the second. We find in this manner that the diameter of Sirius is approximately equal to eleven million kilometres, about seven times the sun's diameter. Thus, while we still lack the systematic measurements demanded by Kapteyn, the distance has been determined of numerous stars in all parts of the heavens, from the most brilliant down to stars of the sixth magnitude. Enough is already known to enable us to assert that while the average dimensions of the stars are somewhat superior to those of the sun they are nevertheless comparable. The sun is, however, a relatively small unit in the stellar world.

At the same time we come to the new notion that the heavens are, on the average, homogeneous; the stars near to us are, in general, neither larger nor smaller than the distant ones. This remark is of importance, because

when generalised it enables us to carry our soundings of the heavens to the limits of the visible world. If we consider the sky to be filled with stars, all of one size and equally distributed in space, it evidently becomes possible to determine the proportion of stars of each magnitude, since the most brilliant stars must necessarily be the nearest. Calculations made on this assumption lead to the result that the stars of any given magnitude are four times as numerous as those of the class immediately superior in point of brightness. Now this is actually what is observed if the stars of the first few magnitudes, which are too few to be treated statistically, are left out of account. There are 321 stars of the fourth magnitude, 1238 of the fifth, 4890 of the sixth; and, as will be seen, these numbers vary in a geometrical progression whose ratio is four. This confirms our hypothesis regarding the homogeneity of the heavens.

Two methods are therefore available for ascertaining the distances of the stars; one, more exact, based on the measurement of their parallaxes, has so far only been applied to a

very small number of stars. The other, less rigorous but applicable to the entire firmament, enables us to measure the distance of the stars according to their brightness. We are now in a position to imagine a sort of model of the universe, showing each star in its actual place. If, placing ourselves outside of it, we looked at this reduced model of our universe we would see a kind of mist, consisting of separate bright spots, and of very irregular density, but of a clearly defined general form. Imagine a large lens, encircled, at its broadest part, by two rings slightly inclined to one another. We know only the interior part of these rings, which alone are accessible to our most powerful optical instruments. The solar system is situated within the lens, and though placed in a region poor in stars it is nevertheless surrounded by a multitude of them; it does not, however, occupy the centre.

If we now direct our attention to the interior of this microcosm, to the brilliant point which marks the place of the solar system, it will be easy for us to understand the appearance of the starry heavens seen from our earth. When

we look in the direction of the greatest width of this cosmic nebula, that is to say, in the plane of the galactic circle, we see a regular swarm of stars. The stars are not more serried in this direction, but they extend out to greater depths; at the same time the two external rings appear to us as two milky trails. These rings would appear entirely separate if we were placed at the centre of the world, on Alcyone; but, seen from the position occupied by us, they partly hide each other, which explains why one-third of the Milky Way appears to be double. If we now regard the remaining regions of the sky we shall find a firmament much poorer in stars. This is because our line of vision is traversing the flattened part of the central mass—that is to say, it is directed along the smallest diameter of our nebula; these are consequently the directions in which the stars are necessarily most scattered. It is what happens when one enters the outskirts of a wood; in front an innumerable multitude of trees, but, looking back, only a few trunks projected against the sky.

We are thus able to evolve order out of

the chaos of stars and to grasp their unity. The double ring and the central cluster form a whole; the Milky Way enfolds and includes our entire universe. It forms the great nebula to which we belong, with all stars accessible to our investigations.

Hitherto we have tried to realise the solidarity of the worlds constituting the Milky Way by geometrical arguments; we shall now demonstrate it by the more convincing proofs of mechanics.

The fixity of the stars is only an illusion due to their extreme remoteness. None of the stars are motionless; all are animated by translatory motions. Now we have to-day the means of determining these motions in magnitude and in direction, because we are able to compute the velocity of a star, both at right angles to the ray of light reaching us from it (this is called the tangential velocity) and in the direction of the ray itself (the radial velocity).

The tangential motions can be ascertained by angular measurements. A star moving in this manner must vary in right ascension and in declination. Halley was the first to suspect,

in 1718, this variation in the case of Aldebaran, Sirius and Arcturus. Cassini, twenty years later, placed it beyond doubt in the case of the last star by comparing the observations made by Richter in 1672 with his own. Since then the researches of the great astronomer Herschel and of many observers have enabled the alterations in the positions of a great number of stars to be traced on the celestial sphere. Naturally, the brightest, and consequently nearest, stars present the greatest angular displacements. The stars situated at the limits of our heavens appear practically motionless; this fact enables the motions of the stars to be determined by the method which we have already explained for the measurement of parallaxes, as it is possible and more exact to determine the motion of a near and bright star by referring its position to reference stars in its vicinity, sufficiently small to enable their angular motion on the sky to be neglected.

On the other hand, the radial velocity of the stars may be measured by the spectroscope by making use of the same principle which enabled the sun's rotation around its axis to be

measured. The spectra of the stars are analogous to the solar spectrum—that is to say, composed of a continuous series of colours crossed by dark lines, characteristic of the different elements contained in the absorptive atmosphere of these stars; now these lines move slightly, either towards the violet or the red, according as the object and the observer are approaching or receding from one another; it is possible to determine, from the magnitude of these displacements, the radial velocity of the star relatively to the earth. The velocity due to the earth's annual and diurnal motions can be easily deducted, and the actual motions of the stars, relatively to the sun, determined by combining their tangential and radial velocities. These motions take place in all possible directions, at speeds varying from ten to fifty kilometres per second; but they are not directed in haphazard fashion.

Let us first consider the case of the sun. If this orb were fixed in position the motions of the other stars, relatively to it, would follow all possible directions without preference for any, and would be of all magnitudes; this is

due to the fact that the sun occupies no special position in the Milky Way and plays no preponderating part in the motions of the heavens. But if, on the other hand, the sun has a motion of its own, stars moving in the same direction, and at the same speed, will appear at rest relatively to it, while stars moving in the opposite direction will, on the contrary, appear to be moving more rapidly. Thus the mean distribution of stellar velocities with reference to the sun will show a predominant direction which is that of the sun's own movement. In the same way, if one stands still in a crowd moving in all directions, all passers-by approach and recede with equal speed, whatever their direction may be, but if the observer also walks, those who are following the same line will appear to approach more rapidly or to recede more slowly than those who are walking at an angle to his path.

Such, in principle, is the method applied by Sir W. Herschel, Argelander and Airy. It shows that the sun is travelling with a velocity of nearly twelve kilometres per second towards a point situated at the centre of the constellation

Hercules, in the northern hemisphere. This point was called by Herschel the *apex*, because the sun, while moving towards it, rises in the heavens.

Now that the proper motion of the sun has been defined the same can be done for every star whose relative motion, referred to the sun, is known. Each star is found to have an apex of its own, towards which it travels without intermission, each at its own velocity; the velocity of Aldebaran, one of the highest determined, reaching 48 kilometres per second. The brightest stars in the sky travel at an average velocity of 25 kilometres per second; the sun must therefore be classed among the stars of slow displacement. The question arises, What is the law of all these displacements? Is it so complicated that its effects are apparently those of chance? The necessary facts for a solution of this important problem are not yet available, but a very original hypothesis of Mädler, a Dorpat astronomer, is worth mentioning. Mädler remarks that all systems, subject to the law of universal gravitation, are animated by a movement of rotation round a centre. This centre need not necessarily be a material

body, as in our solar system, but may be a geometrical point, a theoretical centre of the attraction, as occurs in the case of systems of double or multiple stars, none of which is predominant. Now the system of the Milky Way appears to present the geometrical regularity of a system, subject to a single law of attraction, and one may inquire in what part of the heavens is to be found this "central sun," as Mädler calls it, which controls the movements of all the other suns. It must evidently be sought in the region where the stars move with the lowest velocity, as their motion must increase with their distance from the centre of attraction. Now this occurs in the group of the Pleiades, which are situated in our northern hemisphere and belong to the constellation of Taurus. The Pleiades form one of the most beautiful clusters of stars in the sky; six of them are visible to the naked eye, but photography or the telescope reveal over two thousand gathered in a very restricted space of sky. The motion of Alcyone, the most beautiful of these stars, is almost *nil*, and for this reason Mädler considers Alcyone to be the central sun of

our stellar system, without, however, meaning by this that it controls the motions of the universe, as our sun rules the motions of the planets which circle round it.

It may therefore be considered probable that the milky nebula revolves as a whole round Alcyone, and that the galactic circle is, in the stellar system, the analogue of the ecliptic in the solar system. Our sun, in particular, describes a vast orbit, whose radius is approximately 192 light-years, with a duration of revolution of twenty-two million years—that is to say, about as many terrestrial years as there are seconds in a single year. It must not be forgotten that these figures are only hypothetical and can only be accepted as giving an idea of the magnitude of these motions. In any case they show that the stars of the milky nebula are not independent, and that universal attraction establishes between them the same close connection which unites the bodies of the solar system.

We have still to show how great is the variety of the types found in the sky, though, at first sight, it presents only a number of bright points.

First, we have the nebulæ. They appear to us like milky white clouds, with ill-defined edges, sometimes condensed in a certain number of brighter regions, looking like stars surrounded by an aureole. Some, irregular in shape, are surrounded in all directions by a coma of whitish filaments; others take the form of flattened globules which are visible at times on edge, at others askew or flat.

The number of the nebulæ is considerable; at present more than eight thousand have been counted, and new ones are discovered every year. An American astronomer alone, Mr Swift, has catalogued nearly a thousand; at the Paris observatory M. Bigourdan has undertaken to determine the exact position of all these nebulæ and already several thousands have been accurately located.

At what distance from us do these cosmic masses gravitate? They appear to be at the ends of the world. In any case it has hitherto been impossible to determine the parallax of a single one, and the diffused appearance of their contour would render a determination of this nature particularly difficult. But M.

Keeler has been able to determine the radial velocity of about fifteen nebulæ by observing the change of position of the spectral lines; these velocities are about 50 to 60 kilometres per second. If, as would appear probable, the tangential velocities are of the same order of magnitude, it may perhaps some day be possible to compute the distance which separates us from these nebulæ. If this distance does not exceed twenty million times the distance from the earth to the sun, the tangential motion will have, in a hundred years, transported these nebulæ a distance in the heavens equal to that covered by one of the spider-threads stretched across the focus of our telescopes; probably a century would be insufficient to ascertain this motion, but astronomers are patient, and we may also hope that they will succeed in discovering new methods and in improving the old ones.

When Herschel commenced to attack the nebulæ with instruments of increasing power he observed that some of them were reduced to agglomerations of stars to which he gave the designation of *resolvable nebulæ*, and it was

for a long time a question whether all nebulæ could not be resolved into stars, by the use of sufficient powers of magnification. The use of the spectroscope has supplied a definite answer to this question, and the glory of this discovery belongs to the English astronomer, Huggins. Huggins showed in 1864 that certain nebulæ, seen through the spectroscope, give the continuous spectrum crossed by black lines which characterises the sun, the stars, and matter already condensed, whereas the spectrum of others consists of bright lines on a dark background; that is to say, the spectrum of matter in a state of gas or vapour. The nebulæ of this class, which no telescope can ever resolve, appear to constitute the primordial form of matter in course of condensation, the gigantic ovum from which the stars were developed.

These views, so consonant with the cosmogonical theories of Kant and Laplace, have recently received some remarkable confirmations. Huggins, while studying the spectrum of certain stars of Orion, discovered bright lines extending into the nebula which surrounds these stars. Orion might therefore appear to be a nebula

in course of condensation. The same would appear true of the Pleiades. The photographs of this group, obtained by M. Henry at the Paris observatory, show threads of nebulous matter extending from one star to another, suggesting remains of cosmic substance surviving condensation. Photographs of the nebula of Andromeda have, likewise, revealed within it several gaseous rings, surrounding an enormous, ill-defined central mass.

The sky seems thus to offer us many transitions between the purely gaseous nebula and the star properly so-called. One of the most remarkable of these transition forms is the globular cluster. The isolation of these agglomerations of stars on the dark background of the sky, as well as the regularity of their forms, generally circular or elliptical, force us to the conclusion that they constitute independent systems. The cluster of Omega Centauri is visible to the naked eye in the form of a round nebula approximating in brightness to a star of the fourth magnitude; but under high magnification it resolves itself into an agglomeration of stars from the thirteenth to the

fifteenth magnitude. It is possible to count on photographs up to six thousand stars, although their number must be greater, because, in the centre of the cluster, many of the luminous points must be superimposed.

The stars, in their turn, like the nebulæ, present the most varied appearances, revealing the diversity of their structure. To the naked eye some appear white, some yellow, and some reddish, while the colour of others at times seems greenish and at others bluish. In the neighbourhood of the Southern Cross 170 stars are contained in a space equal to one-fortieth of a square degree; a score of the brightest ones present all the colours of the rainbow, so that this group has been compared to a splendid jewel studded with precious stones of every possible water.

These differences of coloration, which can be further analysed by the spectroscope, appear to be related to the temperature, one and the same star turning, as it cools, successively blue, white, green, yellow, and then red. This shows us that all parts of the primitive nebula have not aged with equal rapidity, and here

we are faced by a fact which appears paradoxical but which has to be accepted and worked into the structure of our cosmogonic speculations. If we consider a group of neighbouring stars, apparently of like origin, it would seem natural for the coolest to be also the smallest. This, however, is not the case, and no simple relation exists between the magnitude and the colouring of the stars. Thus in the group ζ Orionis are comprised six stars. A, of fourth magnitude, is white; B, of eighth magnitude, blue; C, of seventh magnitude, wine red; D, of eighth magnitude, dark red; E, of ninth magnitude, white; and F, of eighth magnitude, pale grey.

It is, however, to the study of the variable bright stars that we owe our most suggestive discoveries; better than any other it leads us to realise the intensity of the life which animates the plains of the heavens.

Sometimes stars, previously unknown, burst into light; these are the new or *temporary* stars, so called because they seem born only to be at once extinguished or to become barely visible. The systematic study of these *novæ*

has been made possible by the use of photography; Miss Fleming, alone, at the observatory of Harvard College, has been able to discover ten. The appearance of stars of this kind has always filled mankind with astonishment and anxiety; they have been looked on as "omens in the sky" and the forerunners of great events on earth. By rare good fortune one of them, the celebrated Peregrina, was observed by one of the greatest astronomers of all times, Tycho-Brahe; we give in his own words the description of this memorable observation:

"When in 1572 I left Germany to return to the Danish Isles, I stopped at the ancient and beautifully-situated cloister of Herritzwaldt, belonging to my uncle, Steno Bill, and I got into the habit of remaining in my chemical laboratory until nightfall.

"One evening, 15th November 1572, while contemplating as usual the dome of the heavens, whose aspect is so familiar to me, I saw with inexpressible astonishment, near the zenith in Cassiopea, a radiant star of extraordinary size. In my surprise I did not know whether I should

believe my eyes. To persuade myself that this was no illusion, and to collect the testimony of other witnesses, I called out the workmen engaged in my laboratory and inquired of them, as well as of all passers-by, if they saw, as I did, the star which had appeared so suddenly. I heard later that in Germany carters and other working men had apprised astronomers of a great apparition in the sky, which caused a renewal of the usual jokes at the expense of men of science.

"The new star was tailless and free from any nebulosity; it was in all points like the other stars, only it scintillated more than stars of the first magnitude. It exceeded in brightness Sirius, Lyra and Jupiter, and could only be compared to Venus at her least distance from the earth. The distances from this star to others of Cassiopea, which I measured the year following with the greatest care, have convinced me of its perfect immobility.

"From the month of December 1572 its brightness began to wane, being then equal to Jupiter; but in January 1573 it had become less bright than Jupiter. It reached the second

magnitude in April and May, the third in July and August, the fourth in November, the sixth in February 1574. The following month the star disappeared without leaving any trace visible to the naked eye, after having shined for seventeen months."

No one has seen it since, and the phenomenon observed by Tycho-Brahe would have remained inexplicable if later observations had not put us on the track again. In 1638 Halwarda discovered in the Whale a star of the third magnitude, which disappeared at the end of a few months; in 1639 he saw it again in the same place and of the same brightness. It again disappeared, to reappear a third time, and since Halwarda's time it has followed the same course. This marvellous star, Mira Ceti, is periodic, visible during four months, invisible during seven. It has therefore a period of eleven months.

Since then many periodical stars have been discovered—about two hundred, with periods varying from two years to a few hours. Many stars have also been discovered with irregular or unknown periods. All these observations

supply a basis for the solution of the enigma presented by Peregrina; for if we succeed in explaining the nature of the periodical stars we shall also understand the nature of the temporary stars, on the assumption that their period is longer than the duration of our observations. It is also possible that the complicated course observed in the case of some periods may be due to perturbations caused by the influence of neighbouring stars.

The periodicity of one of these variable stars follows a law of extreme simplicity. This star is Algol in the constellation Perseus. Algol never goes out. During two and a half days its brightness remains constant and of the second magnitude, then it varies during nine hours, with a minimum lasting eighteen minutes, during which its brightness decreases to that of a star of the fourth magnitude, after which Algol resumes its original brightness, being thus characterised by a constant brightness interrupted by partial eclipses. Many are the explanations advanced to account for this phenomenon. Already in 1667 Bouillaud maintained that the surface of the stars is not

uniformly luminous and that their rotation round an axis exposes to our view portions of their disc possessing different lighting powers. The existence of solar spots seems to corroborate to some extent this explanation, which was taken up again by Zöllner. Maupertuis, with greater daring, likened the periodic stars to millstones, which sometimes show us their edge and at others their flat side. There is another hypothesis, maintained and developed with great talent by Pickering, which considers Algol as a binary system, consisting of a large bright star and a smaller darker star, in the rotation of which system the dark star partly hides, "occults," the bright star and causes the decrease of brightness observed.

If we apply the results of observation and the law of universal gravitation to this hypothesis we are led to the following conclusions: the diameter of the dark companion of Algol would be equal to that of the sun and the diameter of the bright star would be about a fifth longer. The two stars, situated about five million kilometres apart, would turn round a centre situated at about three-quarters of the distance

which separates them. It is even possible to calculate the masses and the densities of the two stars so that, thanks to Pickering's hypothesis, the binary system of Algol would be nearly as well defined as our own solar system.

These inferences lacked the confirmation of experiment, but not for long. Vogel observed the spectrum of Algol at the moment when, according to Pickering's hypothesis, the velocity in the line of sight is greatest—that is to say, a quarter of a period before and after occultation. He was able to observe a noticeable displacement of the spectral lines, which deviated towards the red a quarter period before the minimum, and towards the violet a quarter period after. Thus, during its presumed period of rotation, Algol has a variable velocity in a direction sometimes toward us, sometimes away from us. It is thus clearly established that this bright star revolves around a star invisible to us, and Pickering's theory is established among the accepted truths of science.

All the variable stars present problems analogous with the one just discussed. The most frequent case consists in a continuous

variation of light, with long or short periods. Spectroscopic investigation shows that also in this case the variable star describes a closed orbit; but occultation by a single companion does not appear sufficient to explain the continuous variation of brightness if the stars are considered to be spherical and their orbits circular. An ingenious hypothesis, which deserves great consideration from the name of its author, Sir Norman Lockyer, considers each of the bodies revolving round a common centre to consist of clusters of meteorites, agglomerated with increasing density from the periphery to the centre, and suggests that the continuous variation of luminosity is caused by the interpenetration of two such clusters, which, by giving rise at the same time to numerous collisions between the meteorites, would rapidly increase the temperature of the system, and thus explain the sudden blazes which sometimes affect the brightness of variable stars.

This hypothesis is superfluous; astronomers prefer, as a rule, to continue to consider all variable stars as binary systems to which

they can apply the explanation which was accepted in the case of Algol; for this it is sufficient to imagine the two companions as neighbouring flattened spheres, or ellipsoids of revolution, turning in a plane which passes through our eye. The apparent surface of such a system will vary continuously, causing the light emitted in our direction to vary in the same sequence. Such is the theory applied by Myers to a number of variable stars, and the conclusions which he reaches are sufficiently original to be worth mention.

Let us take, as an example, the variable star β Lyræ to explain the periodical variation of its brightness. It is sufficient to suppose that it consists of two slightly flattened stars, one bright and relatively small, the other larger and less bright. These two masses would revolve one around the other, almost touching, and the mean density of the matter composing them would be only half that of our atmospheric air. According to this last datum β Lyræ would not be a completely condensed system, but would represent a nebula in course of transformation into a binary system, that is

to say, a system formed of two twin stars. It is clear to what consequences Myers's hypothesis leads. Extended to the other variable stars it shows us in synthetic fashion the successive stages of the evolution of a nebula in course of condensation. "ζ Gemini and W Virginis present practically to our view the segmentation of a nebula, the birth of a binary system. β Lyræ and V Pegasi show us the segmentation nearly complete. In S Voiles and S Cancri the separation is completed, but for one of the components the work of condensation is barely commencing. In Y Cygni the components seem to have developed concurrently and to be two twin stars. Finally, in Algol, which forms the last link of the chain, one of the components is entirely extinct, and is probably approaching the end of its existence as a luminous body, whereas the other is still a radiant sun."[1]

Thus the study of the "obscure brightness" of the stars has shown us the infinite variety of the worlds peopling the heavens and has justified M. Janssen's audacious exclamation:

[1] André, *Traité d'Astronomie Stellaire*, vol. II. p. 309.

"Star, send me a single one of thy rays and I will tell thee what thou art!" However, our enumeration is incomplete; in the midst of the innumerable incandescent stars a single cold one, Algol's companion, has been discovered by chance. But the universe is full of these dead stars, though we are blind to their existence, and if all these orbs could suddenly blaze forth great would be the increased beauty of the heavens! We cannot rely on the method which revealed Algol's companion for the discovery in space of these obscure orbs. It is only occasionally that one of these orbs interposes itself between our eye and a bright star. But science has other resources. If we remember how Leverrier discovered the existence in the solar system of the hitherto unsuspected planet Neptune, revealed by perturbations observed in the other planets, we shall understand the principle which enabled Bessel to conquer this invisible world. A star, without any near neighbours in the heavens, should move in a straight line, or rather describe an almost circular trajectory round Mädler's central sun; but if it has invisible companions

its trajectory will be perturbed by their presence, and the study of these irregularities may enable the position and the size of these companions to be determined.

Bessel selected for his investigations two of the most beautiful stars in the heavens—Sirius, Canis Majoris and Procyon, Canis Minoris. He had determined their positions relatively to neighbouring stars during a period of twenty-four years, from 1820 to 1844, and had acquired the conviction that certain anomalies presented by the motions of these stars must necessarily be due, in each case, to the presence of a companion. All that remained to be done was to determine the position and the magnitude of these two supplementary stars by an application of the laws of universal gravitation. Now, in 1862, Clark of Boston discovered, in the vicinity of Sirius, a star of the tenth magnitude, occupying practically the position indicated by theory. The observation of this star, carried out with great care and detail, furnished a brilliant justification of Bessel's method. The companion of Procyon was discovered in 1896 by Schoeberle

at the Lick observatory, in the form of a large reddish star, whose weak light is lost in the radiant brightness of Procyon.

We have mentioned these two examples in which theory owed its confirmation to the chances of observation, because the companions of Sirius and Procyon happened not to be completely extinct. But many other cases exist in which an equally reliable interpretation is possible. The Star C of ζ Cancri progresses on the average in the sky at the yearly rate of one half degree, but this displacement is anything but regular. Every eighteen years a sensible backward motion takes place, lasting about two years. It has been possible to explain this anomaly by the existence of a dark companion, whose elements have been determined by the perturbations of star C. The astronomy of the invisible has thus its own method, which is truly slow and tentative, but sure in principle and rich in results.

The discoveries of astronomy have revealed to us the multiplicity of the forms which people the universe. They show us a world which is

alive, and whose parts are in motion and in course of transformation. It is a great step forward to have determined its present condition, but these observations justify still more important conclusions. Every point of the heavens shows us a phase of the history of the universe. This was in the mind of Herschel more than a century ago when he said, "The heavens resemble a luxuriant garden, containing the greatest variety of products in different stages of existence, and its present examination enables us to extend our experience over an immense duration. The spectacle which it offers is as though we could see, taking place under our eyes, all the various acts of vegetable life from germination, flowering and fecundation to desiccation and final decay."

Our universe appears to us at its origin in the form of a great flattened nebula, consisting of gaseous matter practically uniformly distributed in space and animated by a movement of rotation. Little by little its substance condenses into flakes which are gradually separated from the whole by attraction, each forming the embryo of a new world, which will develop

little by little. The filaments of cosmic matter connecting it to the whole are gradually absorbed by the principal mass; the elementary nebula becomes rounded and then splits into two masses of corresponding importance, or even into a greater number. The first case is the most frequent and gives birth to these binary systems, these Siamese twins whose abundance has been demonstrated by observation. In other cases, practically the entire mass of the nebula condenses to form a central sun surrounded by a variable number of satellites. All these stars are ageing, and will die. The heavens are a cemetery of stars.

The conceptions which we are justified in inferring from the positive facts of science go no farther. The problem of origin and end is no nearer solution for the universe than for man himself; perhaps it is devoid of meaning, because evolution has neither beginning nor end.

THE ORGANISATION OF MATTER

CLASSIFICATION is a necessity, for all science is co-ordinated knowledge, but classifications may be misleading. They are apt to erect barriers between things which Nature has connected by continuous gradations. Nothing could be more distinct than the islands of an archipelago, but soundings show submerged ridges connecting them to each other and to the common sea-bed on which they rest.

Thus the division of Nature into three kingdoms is as old as human thought—an animal, a plant, a stone. Nothing could be more simple and distinct, or appeal more readily to the mind, and three is a number dear to the gods. But simplicity exists only in our mind. Nature is infinitely complicated and provides between its types innumerable transitions, such as we find between the three states of matter—solid, liquid and gaseous. It is to-day an established fact that no clear line of demarcation exists

between animals and plants; but we still look on life as a thing apart, a mystery impenetrable to science. But the mystery is being dissipated by investigation. The naturalist searching for a definition of life sees before him forms of increasing simplicity, and finds that the very essence of life vanishes whenever he endeavours to determine it with precision. The physicist is reaching the same conclusion in the opposite way.

He starts from the notion, inferred from superficial observation, of a matter really inert and dead; but closer study soon shows him the prodigious activity hidden under this apparent inertia. He sees forces at work—diffusion, osmosis, cohesion, crystalline, catalytic and electric actions organising matter, creating forms and endowing brute substance with many of the characters of living beings. He also realises his incapacity to delimit his domain and to say where the mineral kingdom ends and where life begins. But without abandoning the most prudent circumspection he will at least be able to assert that many phenomena hitherto considered characteristic

of life belong to brute matter and derive from physico-chemical causes.

The living being is characterised by its products, by its organisation and by its functions. Let us first consider its products. It was long believed that organised beings elaborated and utilised special products. It was the custom to speak of Nature's mysterious laboratory and of a vital force different from and additional to the forces which determine ordinary chemical phenomena. All chemists, and all naturalists, at the beginning of the nineteenth century, still held this "vitalist" doctrine, and Berzelius was able to write in his classical *Treatise of Chemistry:* "In animated nature the elements seem to obey entirely different laws from those of inorganic nature . . . If we could discover the cause of this difference we should have the key to organic chemistry; but this cause is so completely hidden that we have no hope of discovering it, at least in our day."

We all know how vitalism has retreated before the valiant attack of a legion of chemists with M. Berthelot at their head. Little by

little the various compounds elaborated by life have been reproduced synthetically in the laboratory. It is no longer necessary in order to obtain them to bring into action any forces but those which govern brute matter. However, the victory is incomplete; the bodies reproduced by synthesis are mere products of excretion, the waste materials of life, such as urea, the essences and the perfumes, whereas life itself is concentrated in the protein substances sometimes called albuminoids, because albumen is one of them. They are difficult to tackle. Even to isolate them in a pure state is a very difficult operation. They represent the most complex and unstable form of chemical compounds. That is the reason for the part they play in life. But they are to-day the object of study of a whole army of chemists. The German school, led by Fischer and Kossel, has already succeeded in disintegrating their molecular aggregations; this is the inevitable preliminary work, and we may expect a Berthelot to arise before long to carry out the synthesis of the albuminoids. Physiological chemistry has also been occupied with the action in living

matter of these strange products, *enzymes* or *zymases*, which are frequently designated under the generic name of *soluble ferments*, to indicate that they transform the substance of living beings, as a pinch of leaven modifies a batch of dough.

Enzymes are the soul of the many vital reactions, the demon ceaselessly busy tying and untying the molecular bonds. Already considerable numbers have been discovered and isolated, which all present a common character. Their mass is always very small in comparison with the mass of the body transformed; rennet, for example, can curdle ten thousand times its weight of milk. Thus the enzymes act like ferments but without being organised; and, as a matter of fact, organised ferments act only through the enzymes secreted by them, as Buchner established in 1897 in the case of the enzyme of yeast.

The action of enzymes is beginning to be understood. M. Bertrand has succeeded in the case of some of them, the *oxidases*, in determining the function of the manganese of which they contain an infinitesimal proportion.

And by entirely different means Bredig and von Berneck have shown that the action of enzymes is not connected with any unknown vital property. If two rods of platinum, gold or silver, are immersed in water or any other isolating liquid, and connected to the two poles of a battery of accumulators, and, after having been placed in contact for a moment, they are separated, an electric arc is established within the liquid between the two rods; the liquid now gradually loses its transparency. It contains in the form of an impalpable powder, invisible to the most powerful microscope, the fragments of the metal pulverised by the arc. In this state of extreme sub-division, called the *colloidal* state, metals present some very peculiar properties.

They are coagulable by heat, by salts, by acids and by bases. They can, by their presence, activate certain chemical reactions, decompose sugar, transform alcohol into acetic acid. Their function appears then to be entirely similar to that of enzymes, because an infinitesimal proportion of the metal suffices to determine the reaction; thus one part of colloidal platinum

can decompose more than a million times its weight of oxygenated water, just as rennet acts on milk.

And what is still more remarkable, this platinum is rendered inactive, killed, in a word, by heat, sulphuretted hydrogen, corrosive sublimate, that is to say, by the very agents which kill living matter, so that the mineral kingdom produces bodies which might by their action be confounded with the apparently most characteristic agents of life. The course of physiological chemistry is thus clearly traced. It gradually compels the reactions of living matter to enter the enlarged field of general chemistry; and if its work is far from complete nobody could to-day be found to repeat the famous *ignorabimus* of Du Bois-Reymond, and to declare that in life there are things which will always escape scientific research.

But, more than by its products, life is characterised at first sight by the forms which it creates—composed forms which are reproduced indefinitely according to the laws of heredity, elementary forms constituted by cells and

micellæ. Animated matter is composed of cells and micellæ, as brute matter is composed of molecules and atoms. But it is not sufficiently realised, and the fact must be insisted upon that this brute matter is not a simple pile of molecules and atoms. It has a very complicated architecture, belonging to the most varied types, which frequently present to a striking degree the characteristic forms of living beings.

This power of organisation of matter is visible in the crystal. We have all admired in a chemist's shop window, or in a display of chemical products, crystallisations of bismuth, of sulphate of copper or of alum, jewels whose facets have been cut by the forces of Nature, or these trees of Saturn and of Diana in which lead or silver crystals imitate, roughly and superficially it is true, the appearance of plants. No particular conclusions can be drawn from the contemplation of this rigid and dead matter. What would be interesting to see is the birth of the first crystal within a transparent solution, which is being cooled or concentrated by evaporation.

A German scientist, Von Schrön, believes he was able to observe this birth and describes

it as follows. Within the homogeneous liquid a small globule is suddenly seen to appear, enclosing a thread-like net, similar to the chromatic filament of living cells; soon the globule grows into a sort of ring which immediately alters its form, producing an angle, to which the future crystal will be attached, then a second angle appears, and between the two, like a very thin line, appears the axis of the crystal, which is gradually completed. This elementary crystal is free to move in the liquid. At the same time it can give birth to other crystals—in a word, it can reproduce itself by the same processes met with in the reproduction of living cells—either by splitting into two crystals which recede from each other, rotating around themselves, or by forming on one of its angles a new crystal which detaches itself; this is *gemmation*. Or, finally, the new individual, formed by *endogeny* inside the crystalline mother-cell, reaches the surface and dives into the food-supplying liquid, where it grows, and in due course reproduces itself according to the laws of heredity.

Von Schrön, Benedikt and other physio-

logists attach to these analogies an importance which it is reasonable to consider exaggerated. However great their interest, they do not entitle us to destroy the partition which, in the present state of our knowledge, separates dead matter from living matter. But the question may be examined in a different light.

If a hot saturated solution is allowed to cool, sometimes crystals are formed in it, but more frequently it remains limpid. It is then what is called supersaturated. In this state it has many points of similarity with a culture-bouillon sterilised by heat. It can, in like manner, be preserved unaltered in sealed tubes or in vials protected against the introduction of external germs by a plug of cotton-wool inserted in their necks. But if the protecting plug is removed, or the tube unsealed, numerous crystalline groups are frequently found to form in the liquid mass, pervading it little by little, just as the bouillon under similar conditions gradually fills with swarming colonies. Both phenomena have the same explanation—crystallisation requires in this case the presence of a crystalline germ, just as life needs a living germ. Both

exist in the air and invade with it the liquid which they fertilise.

Contagions and epidemics spread in the mineral world by a similar process. Railway engineers frequently find that all the rails in the same region have become brittle and require replacing at the same time. A few years ago, it was observed that the tin buttons of certain Russian regiments were all becoming brittle and breaking up into thousands of grains. This disease of the buttons was shown to be distinctly epidemic. If a uniform of one of the contaminated regiments was brought to an unaffected district, numerous cases of the disease occurred in its vicinity.

The explanation of this fact is simple. Tin can be transformed by the severe cold of winter into an extremely crystalline variety—gray tin; but this transformation can occur at a higher temperature in contact with an existing crystal. Thus the buttons attacked produce, by their pulverisation, thousands of crystalline germs, which give rise all around them to the same modification.

But it is not crystals alone that imitate the

forms and the properties of living matter. If we desire to reproduce these forms as faithfully as possible, we must not make the attempt with solid bodies, but with liquid or viscous mixtures similar to those found in living tissues.

It is then possible to bring into action forces of the most diverse kinds—capillarity, osmosis, diffusion, convection of heat. M. Bénard, by utilising the vortices produced in liquids disturbed by local inequalities of temperature, has succeeded in reproducing with striking exactness the cellular disposition of vegetable tissues. Quincke with his foam cells, and Harting with his jellies, are also working at *synthetic morphology.* Bütschli of Heidelberg is pursuing the same results by analogous means. "He manages it," says M. Raphaël Dubois, "by mixing with certain precautions linseed oil, an alkaline carbonate and water, or instead, oil and yoke of egg, just as if he were making a mayonnaise sauce. It is cookery, but very strange when seen through the microscope. Not only does it resemble the fundamental substance of cells, reduced to its most simple

form and highly magnified, but it moves, it changes its place and its form like a monad or an amœba. And Professor de Herrera of Mexico, by modifying Bütschli's experiments, comes to the conclusion that most of the physical properties of protoplasm can be imitated with alkaline oleates or soaps."

We must not misrepresent the trend of these experiments. Their authors had no intention, by such methods, of bringing about the synthesis of living matter. These imitations are neither mere playthings, nor are they pretentious attempts to create living beings. They are only intended to determine the part played in living matter by the different physico-chemical forces.

Of all these factors of life none appear more important than diffusion. The bean, which remains inert as long as it is dry, only commences to germinate when the water, which causes it to swell, gives rise in its substance to differences of concentration and sets in action the forces of diffusion and osmosis.

Let us explain what these phenomena consist in. If we pour some water into a tumbler

and then cautiously add some coloured alcohol, or, more simply, some wine, this liquid, being lighter, forms at first a distinctly separate layer on the surface of the water, just as oil would do, with the difference that whereas the oil would remain permanently on top of the water, the alcohol gradually mixes with it, and being coloured enables this gradual diffusion to be followed. The water, on its side, travels in the opposite direction and diffuses into the alcohol. All miscible liquids exhibit similar phenomena. If the liquids are separated by a permeable membrane the diffusion is known by the name of osmosis. Thus in 1748 Abbé Nollet studied the osmotic exchanges between water and alcohol separated by a pig's bladder. The experiment may be made with substances dissolved in liquids, and it is then found that the bodies in solution traverse the membrane at very different speeds, according to their nature. If, for example, on one side of this membrane there is pure water and on the other an aqueous solution of sugar and molasses, the sugar, a crystallisable body, will be seen to cross the partition rapidly, whereas the non-

crystallisable molasses will only diffuse with extreme slowness. This is the principle of the purification of sugar juice introduced by Dubrunfaut and used in all sugar houses. This observation may be generalised. We may follow the English physicist Graham and say that all natural bodies are divided into crystalloids, which diffuse readily, and colloids, which diffuse slowly.

This classification is easily explained if we consider that organic substances not easily crystallised—that is to say, colloids—have undoubtedly a much larger molecule than crystallised bodies. Thus Hofmeister attributes to the albumen of the blood the formula C_{450} H_{720} N_{116} S_6 O_{140}; the albumen molecule is therefore built up of 450 atoms of carbon, 720 atoms of hydrogen, 116 of nitrogen, 6 of sulphur and 140 of oxygen. It weighs ten thousand times more than an atom of hydrogen and 250 times more than a molecule of salt; it is therefore natural for it to be much larger and less capable of slipping through the pores of membranes.

On the other hand, there are great differences between these membranes; some are much

less permeable than a pig's bladder or vegetable parchment; such are the so-called semi-permeable diaphragms, which let the water or the dissolving liquid through but hold back entirely the bodies in solution, even crystallisable ones such as salt or sugar. The membranes of living tissues, in their infinite variety, act like sieves with various-sized holes and sort out automatically the products necessary to life. The albuminoids and analogous products, due to chemical reactions occurring inside the tissues, are in general retained by the relative impermeability of the tissues, whereas the waste materials of life, which are frequently crystallisable, such as urea, are eliminated, thanks to their greater diffusibility. Thus diffusion is life, or at least one of its most essential elements.

M. Stéphane Leduc, Professor at the School of Medicine of Nantes, has demonstrated this important function of diffusion by some remarkably clear experiments. What is necessary to constitute an inorganic tissue analogous to organic tissues? Simply to add, drop by drop, salt water dyed with Indian ink to some pure water spread in a thin layer in a flat-bottomed

vessel, or instead, to drop some potassium ferrocyanide on a thin layer of gelatine; the dye will show the cellular disposition, produced automatically by diffusion. According to the conditions of the experiment, we obtain polyhedral cells, or fibre-shaped cells, or cells with ciliary prolongations or with dendritic ramifications as in nerve-cells. All these cells have their nucleus; they are the seat of internal movements, and osmotic exchanges take place from one to the other. As early as 1866, Traube, a chemist and wine merchant of Breslau, had produced real artificial cells by letting fall a drop of dissolved copper sulphate into a solution of potassium ferrocyanide; the reaction of the two bodies formed, on the surface of the drop, a gelatinous envelope of copper ferrocyanide, but the utricle formed in this manner was incapable of growth. M. Leduc has reached much more suggestive results by adding to the liquids used by Traube other suitably selected substances. The drop, or the initial cell, undergoes a considerable development in a time varying from a few minutes to several days, and resulting in the production of a real cellu-

lar tissue, which presents two of the essential characteristics of life—organisation and nutrition.

The following is an example recently presented to the Academy of Sciences. A drop, measuring about a millimetre in diameter, and containing a solution of one part of copper sulphate to two parts of sugar, is dropped into a nutrient liquid consisting of water containing gelatine, potassium ferrocyanide and traces of salt. At the end of a few minutes pseudo-vegetations are seen to appear with stems, twigs and leaves, like sea-weeds, terminated by thorns, clusters and catkins; the whole may reach a development of fifty centimetres. These artificial plants possess some of the properties hitherto considered peculiar to living beings; they absorb and eliminate; they are sensitive to poisons and anesthetics; chloroform arrests their development, light and heat favour it, giving rise to the effects of orientation and heliotropism which are also manifested by most plants.

The artificial cells manifest another property if left to themselves. They end by dividing up into a great number of cells, and the character

of this transformation presents a great analogy with the segmentation of the germinal disc in an incubated egg; it therefore helps us to understand what takes place in this transformation, one of the most mysterious in life. The high temperature of the egg produces an evaporation which concentrates the superficial parts and determines diffusion currents, which cause the segmentation of the mass.

But the most suggestive of M. Leduc's experiments appears to be the reproduction of the phenomena of *karyokinesis*, that is to say, the strange and complicated process by which the cleavage of cells is brought about. Two small globules situated close to the nucleus and called attraction spheres become separated, travel to the extremities of the cell and throw out radiating fibres. At the same time the chromatin filament, a long thread coiled up in the nucleus, splits into lengths which form a star at the centre of the cell, then each of these lengths divides and the fragments execute regular evolutions like a ballet figure in the protoplasmic mass. Finally a partition separates the cell into two cells, in each of which

are reproduced the nucleus and all the elements of the original cell.

Now all these actions, which appear to defy analysis by their complexity, are easily explained by diffusion. If we let fall into a liquid mass a drop of coloured saline solution to represent the nucleus, and then, on either side, a drop of a more concentrated solution, they repel each other as the attraction spheres do in the living cell. At the same time around them appear, in their regular order, all the figures, all the movements, and all the phenomena of karyokinesis. No example could furnish a better proof of the utility of this synthetic morphology, which throws light on the most intimate mechanism of life.

Experimental proof of the part played by diffusion in vital phenomena is again found in the startling experiments which, since 1899, Professor Jacques Loeb of the University of San Francisco and Professor Yves Delage of the Sorbonne have carried out in *artificial parthenogenesis*. Eggs of sea-urchins and starfish have been fertilised and brought to a remarkable degree of development by the sole action of

saline solutions. It has thus been possible for the function of the male cell to be discharged by an entirely inorganic liquid, apparently acting in a purely physical manner by determining a diffusion-current, which deprives the egg of a certain quantity of water. The eggs fertilised by chemical means were able to develop into larvæ, and, completing their metamorphosis, to grow into sea-urchins and starfish similar in all points, notwithstanding the smallness of their dimensions, to the most fully formed adults of their species; but more remarkable still, parthenogenesis gave rise to a new species, a sea-urchin with hexagonal symmetry, whereas the symmetry of the present-day types is almost invariably pentagonal.

The investigations of Messrs Stéphane Leduc, Loeb and Delage are truly scientific. They furnish new facts for the explanation of life. The researches of Mr Burke have had a more brilliant destiny; they startled, for a few hours, the scientific world and puzzled even the general public, which began to think that a synthesis of living matter had at last been realised.

In his youthful eagerness Mr Burke had

turned to radium, the great generator of energy; he had sown some grains of it on some sterilised bouillon, and a few days later had seen a number of vesicles appear, showing all the characters of living cells. The experiment had already been made by M. Raphaël Dubois, who describes it as follows:

"In consequence of my ideas on the radioactivity of life, I placed one day a small crystal of chloride of barium and radium, with all necessary aseptic precautions, on a gelatinous culture-bouillon for luminous microbes. In my nutrient colloidal jelly I soon began to see a considerable quantity of little corpuscles which sank rapidly into its depths and at the same time increased in size. Their general appearance recalled so closely a bacterial culture that M. Laveran of the Institut Pasteur, to whom I showed one of my tubes at the Societé de Biologie, exclaimed, 'Why, these are moulds!' They were not moulds, but merely granulations presenting the appearance of large vacuoles, and what is stranger still, the largest of them were in course of separation. Some greatly enlarged photographs were made, and I sub-

mitted them at another sitting. My learned friend, M. Henneguy, professor of cytology at the Collège de France, said to me on this occasion, 'They look like frogs' eggs in course of segmentation.'"

Naturally, no scientist was misled by these appearances, of which Sir W. Ramsay has supplied a very simple explanation: the vacuoles in question are simply gas bubbles due to the decomposition of the water by the emanation of the radium. It therefore appears necessary to make a selection among these pretended syntheses of life and to retain only those which teach a lesson regarding the real mechanism of life.

So-called inert matter is not only capable of imitating the forms of living matter, but presents in a certain degree the same functions and properties—as the consideration of the morphological synthesis of M. Leduc has already proved. But nothing could be more convincing than the facts brought forward by an Indian physicist, Mr Jagadis Chunder Bose,[1] professor at Calcutta.

[1] *Response in the Living and Non-living*, Longmans, Green & Co., London, 1902.

Physiological treatises teach that excitability is one of the essential features of living tissues. This excitability, accompanied by other specific features, is presented by the reactions of inorganic matter. A steel spring forced from its position of equilibrium tends to return to it and reacts in its turn on the hand holding it. This is the universal rule of equality of action and reaction. But in the living world things happen differently; we all know that between the nerve, which is excited, and the muscle, which contracts, there are many intermediaries, that the causality is indirect, forming, as it were, a chain of many links, but of which we only know the ends. The attempt has even been made to define the character of organic irritability by instancing the disproportion between its effect and its cause. If a gramme weight is allowed to fall on a nerve the resulting contraction may do much more work than the fall of the weight; but there is no lack, in the inanimate world, of cases presenting a similar disproportion. It is sufficient, as M. Leduc has pointed out, to turn a steam valve in order to start a train or to strike a match in order to blow up a powder magazine.

We must therefore abandon the idea of finding a characteristic and general definition of organic irritability, though this irritability is one of life's most characteristic features. The excited muscle will contract so long as the tissues composing it are alive; as soon as they are dead its contractility ceases. There is, however, another less immediate, but more delicate, criterion of life. The appearance of electric currents as the result of excitation supplies a most sensitive means of investigation, because our instruments enable us to measure the feeblest currents with precision. Mr Bose has had recourse to this criterion, and the originality of his researches consists in his having subjected to the same experiments, with the same apparatus, inorganic substances as well as animal and vegetable tissues.

The method generally adopted by Bose consists in clamping firmly in the middle the body to be experimented upon—muscle, vegetable or inorganic body—and connecting both its extremities with a very sensitive galvanometer in a closed circuit. Any electric action taking place in the body will thus be

immediately indicated by the needle of the galvanometer, and may be measured by the degree of its deviation. The necessary apparatus is provided for recording photographically the indications of the galvanometer and representing the results of the experiments by means of curves. On the other hand, various means are employed for producing the excitation. One extremity of the body under experiment is struck, twisted, subjected to variations of temperature or treated by chemical re-agents, while the other extremity is left untouched. In each case the galvanometer gives the "electric response" to the excitation. The proceeding is not new; but Bose deserves the credit of having generalised its employment and carried it to its logical consequences. In the absence of the diagrams supplied by him, which offer the most convincing of all demonstrations, we shall merely explain, in a general manner, the results obtained.

The fundamental fact is the generality of the electric response; it had been previously observed only in the living muscle, and its abolition by death had appeared to supply a

truly specific characteristic and consequently a definition of life. The same phenomenon is found in a cauliflower stem or a plant of celery; death abolishes it in this case also. But if we take a rod of tin or of any other carefully-annealed metal, the same effect will be produced, and it can be abolished under certain conditions to be mentioned.

One of the most characteristic features of animal life is fatigue. If a frog's muscle is subjected to a series of stimuli of equal force, and repeated at equal intervals, the contractions of the tissue, or the electric reactions indicated by the galvanometer, will at first be equal, and will then gradually become weaker, until a state of permanent contracture is reached. The tissue is *tetanised*. In living animals it is possible to attribute fatigue to a sort of poisoning of the tissues, caused by waste products and toxins, when the supply of repairing elements by the circulating blood is insufficient; and yet a cut and bloodless muscle recovers its excitability after a few moments of rest. It will cause no great surprise if we say that vegetables also present unmistakable signs of

fatigue. The study of vegetable fatigue is greatly facilitated by the persistence of life in the plant. It is thus easy to verify the fact that a cauliflower or turnip stem submitted to a series of identical shocks reacts less and less; but a few minutes of rest are sufficient to restore their original activity. There is nothing characteristic of life in all this. A platinum wire behaves in the same way. Tin, on the other hand, seems at first not susceptible of fatigue, but if it is kept working for several days running it ends like the other metals by getting tired; but rest soon restores all its activity.

The muscles of the heart and certain nerves present at times a typical reaction, the reverse of the preceding one, called *super-excitation.* Identical and repeated excitations produce increasing reactions. Now Bose has observed this phenomenon in plants, and even in metals. A metal kept at rest for a long time seems to fall into a state of indolence or torpor, and can only be roused by repeated stimuli. This phase of the operation is represented by diagrams analogous to the diagrams obtained from cardiac

muscles. Thus the parallelism persists for the three kingdoms of Nature, even down to exceptional cases.

The action of poisons and anesthetics manifests new analogies. Some bodies, such as a weak solution of sodium carbonate, act as excitants; others, such as bromide of potassium, dull the sensibility of a tin rod, as well as of a carrot root or an animal tissue. Chloroform vapour, chloral and formaline in solution, abolish temporarily all sensibility and do not require more than a minute to stupefy a carrot or a radish. Finally, the action of poisons suppresses beyond recovery every trace of electric response; some appear to have a universal action, such as concentrated alkalis and acids, potassium cyanide, and corrosive sublimate. Oxalic acid, which is also poisonous for living beings, acts on metals to such a degree that a solution of one in ten thousand is sufficient to destroy every trace of electric response in them. As is well known, therapeutics furnish numerous examples of bodies which act in small doses as stimulants and in large doses as poisons. This property is of the most general nature, as Bose has shown by the

action of caustic potash, both on vegetable tissues and on tin.

Temperature exercises a familiar action on living beings. Zero and one hundred degrees centigrade form the extreme limits of organic activity, and this is explained naturally by the properties of water, which constitutes the bulk of all living beings. Between these limits there is always an *optimum*, a temperature favourable above all others to life. Now in the case of metals their electric sensibility appears also to depend on the temperature; in an example related by Bose it increases from five to thirty degrees and then decreases to ninety. But it is probable that each metal, like each living being, manifests its individuality by a distinct law of variation.

We shall close this enumeration with a case in which the analogy is even more unexpected. Sight is the privilege of the higher animals. It is, with thought, the highest form of life. Are we therefore to believe that it evades entirely the laws of inert matter? Many scientists do not think so. Some, taking their stand on the existence and the well-known

action of the retinal purple, have developed a chemical theory, which likens the eye to a photographic apparatus; others, observing that the illumination of the retina produces in the optic nerve an electric current, have compared the eye to the so-called actino-electric battery, which only gives a current when acted on by light.

Bose has contributed to the consolidation of this hypothesis by constructing a sort of artificial eye, consisting of a silver cup filled with water and sensitised internally by exposing its concavity to bromine vapour. An electric circuit, analogous to the optic nerve, connects the outside of the cup with the water contained in it and traverses a galvanometer. It is then observed that the exposure of the sensitised part to the light gives rise to electric responses of a very original type which present the same features as the graphical curves obtained from a frog's eye.

All these accumulated facts justify the following conclusion. The attempts in the direction of synthetic morphology, which have been repeatedly made during the last few years,

have been of the greatest use to science. They are not intended to give us, like Vaucanson's automata, a sterile imitation of life, but to supply us with information respecting the forces at work in the living being; and one is surprised to see, from the observations and experiments which we have related, all that inert matter is capable of doing and the extraordinary power of organisation which resides in it.

The vitalist mysticism, which solves the problem of life by words, is thus disappearing before the evidence of facts; and the discovery, on the one hand, of simple forms of life, and on the other of increasingly complex states of matter, is gradually filling the abyss which, in our earlier thought, separated living beings from the mineral kingdom.

The tendency of science is thus leading us to consider life as a physico-chemical phenomenon. But because we have carried the analysis of life so far, it does not follow that we are certain to succeed with its synthesis, and that some day a living cell, capable of reproduction, will be seen issuing from dead matter. Be that as it may, nobody has the right to treat as

an absurdity the search for spontaneous generation or to class it with the squaring of the circle. We know that it is not sufficient, as Van Helmont imagined, to lock up a dirty shirt with some grains of wheat for a mouse to be born at the end of twenty-one days; we do not deny any of Pasteur's admirable discoveries, but we have certainly the right to say with Sir Oliver Lodge, "There would be no cause for astonishment if we succeeded sooner or later in producing in the laboratory a phenomenon which we could not avoid considering as spontaneous generation." The world is far from its end, and science is only beginning.

THE FRONTIERS OF THE SCIENCES

THERE is much talk of science to-day. Philosophers, sociologists and statesmen study its progress and its function, and every one is convinced that science truly exists and forms a whole, whose parts are all interconnected and explain one another. For a consideration one can be shown places where it dwells, those palaces of our modern universities whose front bears graven the word *Scientia*—showing the high esteem in which modern science is held.

It is there, if anywhere, that we must seek this queen of the world. Superscriptions at every step mark the places reserved for the various sciences—here botany, farther on mathematics, farther still chemistry. Everywhere we find the sciences, but nowhere Science. Each separate branch leads its own life and has no relations with its neighbours, unless it lays claim to some of their accommodation or funds. There is little intercourse between the various

laboratories, no wide-open passages from one to the other, and even less interchange of ideas. Everything shows that the unity created by the architect belongs to the façade alone, and that each has methods, principles and conclusions of its own, in which the others take little or no interest.

The library of the university is the meeting place of all the branches and might be expected to supply the common bond. All the sciences are ranged in it side by side according to the system of classification favoured by the librarian, but this admixture does not constitute union, far less unity. The sciences, though they are such near neighbours in all these rows of books, never coalesce, but each develops as if the others did not exist. Even in those encyclopedias which pretend to synthesise modern knowledge they lie side by side but have no organic union.

Specialisation carried to its extreme limits is the necessary law of progress. It alone renders possible the form of hypertrophy characteristic of advanced scientific culture. In his youth the future scientist, having taken a degree which shows that he has the rudiments of general

culture, enters a laboratory, where he will remain for the rest of his life, breathing the same air, imbibing the same doctrines and keeping his brain busy with the concepts of his predecessors; only too fortunate if he possesses sufficient independence and individuality of mind to add a few new ideas to the accepted ones. He has neither time, nor perhaps inclination, to inquire what is happening through the wall in the next laboratory. Some naturalists have spent a lifetime studying algæ or a class of insects; some physicists have never touched an optical instrument; some chemists have devoted their entire lives to the study of a single metal or of a class of salts. It would be desirable that in addition to these specialists who are the workers necessary to scientific progress there should appear on the scene from time to time a genius sufficiently universal to grasp the sum of human knowledge and by an effort of synthesis constitute Science out of the separate sciences.

Humanity has had its Newton and its Leibnitz, but such men no longer exist or have failed to reveal themselves if they do; and the reason is that the tree of knowledge has out-

grown all bounds, with branches so far apart that if some of their branches meet by chance they do not appear to belong to the same tree.

The manner of constitution of the sciences would form an interesting study, showing the grouping of new and accepted truths around their centres of attraction, which gradually grow like crystals in the midst of a solution; but a study of this nature would exceed the limits of a chapter, and we must be satisfied to call attention to two characteristics of this evolution of the sciences. First, the inability of reason and logic to formulate a complete classification of the sciences. The greatest geniuses of every age, from Aristotle and Bacon to Auguste Comte and Herbert Spencer, have made the attempt, but their endeavours clearly followed the constitution of the sciences instead of preceding it; they tried to give logical form to what existed, but proved their complete incapacity to provide in their classifications for future truths. A science never commences by defining its object and surveying and staking out its domains. Facts are accumulated first, then more general observations, and it is only

later, when their accumulation becomes greater, that the need is felt for an orderly arrangement. Aristotle's classifications had this character of contingency, and the development of human knowledge has long ago broken down his classifications. Later and more ambitious classifiers have imagined a general classification of the sciences present and future, but the pitiable failure of their efforts proves their futility.

Of all these attempts the most curious, perhaps, are these of the illustrious physicist Ampère. I should like to reproduce, for the edification of the reader, the synoptic table in which this man of genius mustered all the branches of human knowledge, dividing them into two kingdoms, each being divided into two sub-kingdoms, and so on, until the succession of divisions resulted in thirty-two sciences of the first order, which gave sixty-four sciences of the second, which, in their turn, were divided into 128 sciences of the third order. Among these 128 sciences there are some, I am afraid, such as phrenegietics, cratiography and threpsiology, which will not soon find a place in our curricula; but, on the other hand,

no provision exists for physical chemistry or bacteriology.

We see that the frontiers of the sciences were not founded on logic, but, like the frontiers of nations, have been constituted gradually. In the same way—and this second point has been established to-day by numerous researches—the content of each science has collected round formulæ which had a utilitarian or religious aim. Even mathematics, whose majestic harmony appears as the triumph of human reason, had the same humble beginnings. The laws of number, the forerunners of arithmetic and algebra, were discovered gropingly and by the inductive methods now employed by the experimental sciences. Astronomy had its origin in the observations of shepherds and sailors. Geometry developed out of the practice of land-surveying in Egypt, where the Nile obliterated year after year the boundaries of the fields, and the rules of the "Harpedonaptes," "those who attach the line," gradually grew into the theorems classified by Euclid. Physics and chemistry saw the light in the workshop of the artisan, and zoology

was perhaps born in a stable or a slaughter-house.

The sum of human knowledge has increased gradually, facts have been condensed into more or less general laws, and the whole has been organised from time to time according to the prevailing ideas concerning the interdependence of the various parts; these ideas have changed frequently in the course of time. Thus the production of animal heat, long considered a manifestation of life, was only classified as a chemical phenomenon after Lavoisier's investigations; the solution of sugar in water and of metals in the acids figured for a long time in the same chapter, and even to-day musical intervals are studied as part of acoustics, though they belong to the domain of sensations and have no relation with the object of physics as we understand it to-day.

Every science becomes constituted and defines the object of its study and the aim of its research little by little, by successive additions and eliminations. Each successive century has modified the classifications which the preceding one had framed and considered both logical and

eternal. This is as it should be, because a nation must organise its scientific life, settle the programme of the various branches of instruction, fix the number and the function of their laboratories precisely in accordance with this logic of the day. The following table gives the official classification of scientific studies in *lycées* and universities in France.[1]

Mathematical Sciences	Sciences of Numerical Magnitudes (Arithmetic, Algebra, Trigonometry).
	Sciences of Space (Pure, Analytical and Descriptive Geometry).
	Sciences of Movement (Mechanics).
	Astronomy.
Physical Sciences	Physics.
	Chemistry.
	Crystallography.
Natural Sciences	Zoology.
	Botany.
	Mineralogy.
	Geology.
	Animal and Vegetable Physiology.

This table, though incomplete, gives an

[1] We take here the word science in its most restricted application, leaving out Sociology, Geography and the other branches of knowledge which official classification leaves without good reason outside the circle of official sciences.

approximate idea of the partitions separating the different courses of study, and a glance is sufficient to show how illogical and arbitrary they are. It is surprising to find astronomy classified with the mathematical sciences, since its concrete object of study identifies it more with the experimental sciences. The same may be said of mechanics, which has been turned into an abstract science devoted to discussions on mathematical points and hypothetical forces, instead of teaching the practical issues which are left neglectfully to the technical schools. The division of natural science, according to the three kingdoms of Nature, rests upon the idea of an abrupt demarcation, an idea which science has abandoned, and presents the double defect of perpetuating inaccurate notions and obscuring some of the deepest and truest analogies of nature.

Without dwelling upon this point we recognise that no classification can be irreproachable. The fact remains that divisions, good or bad, exist. Let us see what part they play.

The sciences are in perpetual evolution.

They change their object from day to day with the consequence that programmes must constantly be recast, courses altered and habits abandoned. This is no great matter, or rather it is the very condition of progress and life. But there is another important circumstance to be considered. As living cells are modified by division, so the sciences acquire new life and growth by the creation of *mixed sciences*.

First we have physical astronomy. Thanks to the immortal labours of Kepler, Newton and Laplace, astronomy has reached a higher degree of perfection than any of the other sciences based on observation. The laws governing our system are known with absolute certainty, as everyone can see for himself from the astronomical predictions, which fix beforehand to a fraction of a second the motions of the various planets; and it was reasonable to speak of celestial mechanics in the case of a science whose entire content could be treated deductively. But that is not the whole of astronomy; there is also a celestial physics and chemistry. What is the nature of these stars which the old astronomy

considered only as masses in movement? What is the matter composing the sun, the planets, the stars, the nebulæ and the comets?

The interest of all these phenomena is patent to everybody, and Kepler's laws are impotent to explain them. We receive only one thing from our fellow-travellers through space, namely, radiations, but how varied in range—chemical, luminous and calorific radiations—probably also electro-magnetic waves, like those of wireless telegraphy, and perhaps others hitherto unknown and unsuspected. It will be necessary to examine all these radiations and extract from them information about the distant regions whence they come, organising our investigation methodically by adapting the methods of physics to the new conditions. There is no lack of discoveries made or hoped for. We are beginning to understand the nature of the external layer of the sun and its movement of rotation. We have collected facts regarding the temperature, the chemical constitution and the physical state of the stars. We have processes of extreme delicacy for determining their dimensions and their displacement relatively to our globe;

the study of eclipses is no longer carried out by the telescope alone. All the instruments of the physicist are brought to bear upon the sun at the moment of occultation. And in addition to this physical astronomy does not interest itself only in the distant stars; it studies everything that is beyond our direct reach—the higher regions of the atmosphere, the meteors which invade it, the aurora borealis and the zodiacal light.

This brief enumeration should suffice to justify the right to existence of a new science, connected with astronomy by its field and with physics by its methods of study, but having its own individuality and clearly-defined object.

Physical chemistry, which is barely fifty years old, may also claim a place among the new sciences. It was brought into existence in France through the labours of Sainte-Claire Deville and Berthelot, but has developed chiefly in Holland and in Germany, and has to-day a definite aim, many established results, and a vast field for future work. Chevreul held that "the object of chemistry is to classify matter into types, called chemical species, each characterised by a definite group of physical,

chemical and organoleptic properties." This definition clearly separates chemistry from physics, which studies one by one the different properties of matter, and whose aim is consequently abstract, whilst chemistry deals with a concrete object. Chemistry was too busy with descriptions to be able to recognise reactions as anything but disturbed periods separating two states of equilibrium, and satisfied itself with vague hypotheses regarding affinities. The classical treatises, with their succession of portraits of chlorine, hydrogen, oxygen and their compounds, recall some of the old histories devoted to the description of our kings and their august alliances, which passed over in a line, as unworthy of the notice of posterity, the disturbed periods called either revolts or revolutions, according to their importance.

But in the end molecular revolutions came in for more attention. The investigation of the formation of ethers and of dissociation showed that chemical reactions, like other phenomena, obey laws. Later, Berthelot attempted to solve the problem of chemical mechanics by investigating the heat developed by reactions. The

problem was too complex to be solved by the efforts of any one man, but to-day we have a plan of action and know what to look for, and the entire battery of physics is trained against these struggles of atoms and molecules. A new science is thus developing, with its laws and its technique, and it has already grown sufficiently to give birth to another science, *electro-chemistry*, which has already made itself heard. Physical chemistry has developed chiefly outside of France, but principally in Germany, where it has laboratories, special journals and a whole generation of specialists devoted to its progress. In France official science has only been able to provide two laboratories, one at the Sorbonne and the other at the University of Nancy—little enough for the country of Berthelot and Deville. We must resign ourselves to see physical chemistry becoming a German science.

Physiology, the most living of the natural sciences, has proved its vitality by giving birth to several new sciences. The most important and generally known is bacteriology, associated for all time with the name of Pasteur. Enough has already been said on the subject of this new

science which has rendered so many benefits to humanity. It furnishes the best example of the radical incapacity of the human mind to define a science *à priori*. From the earliest times numerous examples of fermentation were known, but it never occurred to anybody that it might be worth while to study them systematically, until a man of genius observed them through his microscope and revealed a new world. Bacteriology established its utility from the first and had not to wait for money, laboratories or the specialists necessary to develop a science, nor had it to experience the hardships that the other young sciences have had to endure, treated everywhere as outsiders and left without house-room or funds.

Other branches, which are the result of the evolution of physiology directed definitely towards the study of the physical and chemical laws of life, have been less fortunate; however, this evolution raises many interesting problems. A living being may be considered as a transformer of energy and the balance-sheet of this transformation investigated. Again, the fruitful notion of osmotic pressure may be applied to biological phenomena. It owed its discovery

to the Dutch botanists, and after having acquired more definite meaning at the hands of the physicists it is being employed in biology to elucidate questions of such importance as the movements of the sap in plants and the conditions of germination and fecundation. Other subjects are attracting attention: the action of enzymes, so strangely analogous to the action of certain metals in the so-called colloidal state, reduced to impalpable powders; the strange analogies between micro-organisms and certain crystals, and finally the study of the colloids which physicists are just beginning, which should result in valuable information from the physiological point of view, because protoplasm, the fundamental living matter, belongs to the group of colloids. A *cellular physics* is thus in course of slow development; it may still be called physiology, but its methods and technique are borrowed from the sciences of inert matter, its laboratories must be fitted for both, and, what is more difficult in view of our present specialisation, it must find men equally familiar with biological problems and the methods and apparatus of chemistry and physics.

We have considered the practical side of the question, but it presents another. The sciences are developing, and every day their principles and methods are becoming more stereotyped, while new sciences are emerging from the shade and becoming organised in their turn. All this multiplies the points of view from which we regard Nature. Are these views of the world to remain eternally distinct, as if they belonged to different objects, or are they destined to coalesce and harmonise in a vast synthesis? Our mind refuses to admit that Science has no existence and that the many aspects under which the sciences exhibit Nature are not aspects of a single reality.

The problem of the future consists in bringing about this harmony of the sciences foreseen by Taine: "The progress of science consists in the explanation of a series of facts by a higher fact which sums them up. The different sciences can thus be condensed into as many definitions, from which all the truths composing them can be deduced. Then a time comes when we are more daring; we discover the unity of the universe and understand what

produces it. It neither proceeds from anything external to the world nor from any mysterious thing hidden in the world; it proceeds from a general fact similar to the others, from a parent law from which the others can be deduced, just as all the phenomena of weight are derived from the law of attraction and all the phenomena of light from the law of undulations. This law is the final object of science, and if we could rise to its height we should see the eternal torrent of events and the infinite sea of things issuing from it, as from a spring, by separate and divergent channels."

If the fusion of the sciences is ever to be realised, either according to Taine's dream or in some other manner, it must be by the constant communion of all those who work in laboratories. For this purpose it is desirable to multiply the points of contact between the sciences instead of strengthening the partitions which separate them. It would be childish to attempt to secure unity by artificial means. Only the independent action of the sciences, the interchange of ideas and freedom of discussion, can weld them together; only in this way can a

single spirit, the scientific spirit, penetrate all the cells of the hive.

Such a change would offer numerous advantages. The conviction would become general that isolated facts are without scientific interest and should only be studied to ascertain their laws. Meteorology might find it worth while to digest this truth. I also fancy that it would be generally accepted that observation and experiment are the sole avenues of knowledge. This conviction in the past would have spared us long memoirs of mathematical physics. But my chief hope is that in future the type of scientific finality which is merely a survival of the theological spirit will be banished from our arguments. It is difficult to credit the number of false arguments which still cling to our science and send us into cheap ecstasies over the harmonies of Nature. Some may still believe that water increases in volume when it freezes, in order to prevent the ocean from congealing in bulk and destroying all the fishes; though the same phenomenon in winter bursts the vessels of plants and injures the whole vegetable kingdom. It is in fact incredible that this sanctimonious

finality should pervade natural science to such an extent that Professor Metchnikoff seemed very daring in breaking a lance with it in his *Essai de Philosophie Optimiste.*

We have reviewed the many and important improvements which would follow the realisation of a symbiosis of the sciences which to-day tend more and more to separate, but it is not easy to oppose a tendency established for centuries. Let us now see what endeavours are possible, remembering that the problem is a pedagogical one and not a question of authoritative modifications of methods, revisions of principles or re-casting of hypotheses. No one can enact by authority the unity of science. But we ought to make it impossible for science to be made or taught by narrow minds, products of specialisation pushed to extremes. While the sciences are tending to unite scientists must not draw apart in mutual misunderstanding. But the true remedy for this situation, so harmful to the sciences, consists in the systematic adoption of collaboration.

The exasperating infrequency of this collaboration between scientists cultivating different

sciences is one of the most marked symptoms of the situation to which we call attention. And yet two physicists or two naturalists may frequently be seen uniting their forces towards a common end. This association leads, as a rule, to excellent results. An isolated worker is often hampered by a preconceived idea which would disappear before the united efforts of two diverse minds which, striving with the same end in view, would act as a stimulus and a check on one another.

On the other hand, the great industries are showing us every day that certain complex problems (and most problems are complex) can only be solved by a methodical organisation of the work. In metallurgical works the same steel is studied from the physical, the chemical and the micrographic point of view. The most important companies for the construction of electrical machinery employ sets of specialised engineers, who devote their attention to the several terms of the same problem. Germany leads all other countries in this methodical work. The great institution in Berlin, the Reichsanstalt, investigates methodically the properties of bodies

under their various physical, mechanical and chemical aspects. Another series of concordant investigations applied to glass and crystal enabled the great glass-works in Jena to create types of glass and crystal suitable for all the requirements of science and industry.

Why should what is the rule elsewhere be the exception in our universities? Why should the physiologist be so seldom seen working with the physicist, or the geologist with the chemist? It is not because they have nothing to tell one another; it is, sad to say, because they no longer understand one another, but have become complete strangers.

One could wish that those whose task it is to distribute rewards would do all in their power to encourage scientific collaboration. It should be the duty of the great scientific societies of every land, whose members represent the *élite* of the scientific world, to point out, say every three years, the problems which were ripe for solution.

A programme of research, drawn up by a committee of the society, would furnish to the workers in our laboratories what they often

seek in vain, a useful way of employing their activity. I imagine that such a communication would have the effect of orientating in a single direction and towards a common end, efforts which would otherwise have been dispersed in many directions. Then, the society could centralise the work accomplished, make a synthesis of it, controlling the results by comparison; it could summarise the state which the question had reached, point out the progress accomplished and the gaps remaining to be filled. It would thus assume the directing power which belongs to it of right and, though stopping short of creating a dangerous official science, it would, in a measure, bring about that organisation of the sciences which is as necessary as it is difficult to realise.

We have seen that the separation of the sciences and the specialisation of the scientists are the two grave defects of our present scientific organisation. For these defects a palliative and a remedy exist. The former consists in the extension of general scientific education, but the true remedy consists in the *methodical organisation of scientific collaboration.*

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INDEX

Index

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